NAVFAC
Naval Facilities Engineering Command

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Microgrid Design Guide
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Foreword

In accordance with OPNAVINST 4100.5E, Energy Independence and Security Act, 2007, and Lincoln Laboratory: Massachusetts Institute of Technology Technical Report, 1164, the Department of the Navy has been tasked with achieving ambitious energy efficiency, renewable energy, cybersecurity and energy security goals and objectives. As a key tool to help achieve these goals, Naval Facilities Engineering Command (NAVFAC) has developed this Microgrid Design as a primer for a structured approach to energy management.

The intent of this microgrid Design and Reference Guide is to provide Department of Navy (DON) Installations with a basic understanding of microgrid technology and a common methodology to identify requirements and develop conceptual designs. Microgrid implementation should be evaluated through site specific considerations at each respective installation. A microgrid is a network of systems that performs as a strategic tool to serve mission sustainability without relying on the external commercial power grid.

FECs and PWDs shall ensure widest dissemination of this guide. Educating our planners, designers, Chief Information Officers (CIO), utilities staff, and Public Works Officers on the benefits and capabilities of microgrid technology will increase opportunities to implement optimized sustainable solutions to increasing reliability, resiliency, and efficiency of our shore facilities.

This Microgrid Design Guide has been published as Version 1.0. Because of rapid increases in technology, reliability, resiliency, and efficiency solutions are expected to evolve and improve over time and the design guide will go through iterative modernization. If you have questions or concerns, please contact our NAVFAC Public Works SMEs, Michael Savena (michael.savena@navy.mil) or Bill Anderson (bill.anderson1@navy.mil).

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VERSION HISTORY

Version #	Implemented By	Revision Date	Approved By	Date	Reason
1.0	EXWC	December 2016		August 2016	Initial Document

Preface

The Department of the Navy (DON) has developed this Microgrid Design and Reference Guide as an introductory guide for the design and development of microgrid systems at Navy installations throughout the world. In previous years, microgrid projects were executed individually by the different Department of Defense commands, resulting in varied designs.

Microgrids, which are a controllable group of interconnected loads and distributed energy sources, have evolved significantly over the past few years and are moving into mainstream technology. Dramatic changes in the technology, performance, and costs of both renewable energy and energy storage have sparked this development. The research firm Navigant estimates that global microgrid capacity is expected to grow from 1.4 gigawatts (GW) in 2015 to 7.6 GW in 2024; at the end of the 10-year forecasting period, North America is anticipated to be the leading market (Navigant, 2016).

The intent of this Microgrid Design and Reference Guide is to provide the Naval Facilities Engineering Command (NAVFAC) Facility Engineering Commands (FECs) with a basic understanding of microgrid technology and a common methodology to identify requirements and develop conceptual designs. Site-specific considerations for implementing microgrid technology will be at the discretion of the respective installation.

Mission Objectives and Energy Strategy

Military mission resiliency depends on energy security. A microgrid is a network of systems that performs as a strategic tool to serve mission sustainability without relying on an external commercial power grid. Microgrids may also be a key element in a structured approach to energy management, including source optimization and the integration of renewable energy and non-greenhouse gas-emitting power sources.

Installations may leverage this document to develop an energy and microgrid strategy that includes integrating local generation sources and energy monitoring with intelligent and secure electrical distribution system controls. The result is greater energy efficiency, security, and resiliency.

Section 1 of the design guide includes a list of primary drivers and code requirements to which microgrid designs must adhere.

Section 2 provides general background of the microgrid technology and introduces common terminology and system components.

Section 3 discusses the site evaluation/feasibility phases of microgrid projects.

Section 4 addresses post evaluation and feasibility phases of the project process specific to microgrids. The section discusses the alignment with a Design Bid Build or Design Build Request for Proposal package as outlined in Facilities Criteria, FC 1-300-09N, *Navy and Marine Corps Design Procedures* (2015).

Appendix A, Special Topics, provides an expanded look at the rapidly changing microgrid technology. Special Topics is intended to provide brief, but relatively current, information regarding the changing technology available for application in a microgrid. This appendix will be maintained and updated to ensure information is current.

Appendix B, Microgrid Conceptual Design, presents an example of a microgrid-specific design process that aligns with processes and technology developed by the Department of Energy and Department of Defense, and specifically the Sandia National Laboratories (SNL) course book, *Fundamentals of Advanced*

Microgrid Evaluation, Analysis, and Conceptual Design and the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration cyber-secure microgrid project. In addition, the SNL report "Microgrid Cyber Security Reference Architecture" (SNL, 2013) was used to develop the cyber-security strategy.

Appendix C, NAVFAC Platform Enclave and NUMCS [Navy Utilities Monitoring and Control Systems], will provide cybersecurity and platform architectural knowledge and NUMCS.

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Acronyms and Abbreviations

AC	alternating current
AMI	advanced metering infrastructure
AoR	area of responsibility
BCS	Building Control Systems
BOD	Basis of Design
BOP	balance of plant
CIO	Chief Information Officer
CNG	compressed natural gas
CNIC	Commander, Navy Installations Command
CONOPS	Concept of Operations
COP	Common Operating Picture
CS	Control System
DB	Design Build
DBB	Design Bid Build
DBT	design basis threat
DC	Direct current
DER	distributed energy resource
DERGOS	Distributed Energy Resources Grid Optimization Services
DMZ	Demilitarized zone
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOE	Department of Energy
DON	Department of the Navy
DSG	Distributed System Generation
DUSD I&E	Deputy Under Secretary of Defense for Installations and Environment
EISA 2007	Energy Independence and Security Act of 2007
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EXWC	Engineering and Expeditionary Warfare Center
FC	Facilities Criteria
FEC	Facility Engineering Command
GAO	U.S. Government Accountability Office
GW	Gigawatt
HBSS	Host Based Security System
IA/CND	Information Assurance/Computer Network Defense
ICS	industrial controls system
IDS	intrusion detection system
IEEE	Institute of Electrical and Electronics Engineers
IP	internet protocol
IT	information technology
JCTD	Joint Capabilities Technology Demonstration
JP	jet propellant
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of electricity

LNG	liquefied natural gas
MW	megawatt
NAVFAC	Naval Facilities Engineering Command
NCDOC	Navy Cyber Defense Operations Command
NFPA	National Fire Protection Association
NIPR	Non-Classified Internet Protocol Router
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NUMCS	Navy Utilities Monitoring and Control Systems
PCC	point of common coupling
PE	Platform Enclave
PV	photovoltaic
RFP	request for proposal
RMF	Risk Management Framework
ROI	return on investment
SC	supervisory controls
SCADA	supervisory control and data acquisition
SDN	software defined networking
SECNAV	Secretary of the Navy
SECNAVINST	Secretary of the Navy Instruction
SIPR	Secret Internet Protocol Router
SNL	Sandia National Laboratory
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability and Security
TBD	to be determined
UCS	Utility Control Systems
UFC	Unified Facilities Criteria
UFGS	Uniform Facility Guideline Specifications
UPS	uninterruptable power supply
V	Volt
VA	Department of Veterans Affairs
VHE	Virtual Hosting Environment
VPN	Virtual Private Network
VPP	virtual power plant
WAN	Wide Area Network

SECTION 1

1 Microgrid Document Reference Guide

Microgrids involve multiple aspects of electrical design, including generation, renewable energy, storage, and security and control systems. Table 1-1 a partial list of significant relevant guidance documents.

Table 1-1. Microgrid Reference Guide

Navy Policy, Goals, and Instructions		
Department of the Navy	*Navy and Marine Corps Smart Grid Capability Development Document*	6 Mar 2014
FC 4-141-05N	*Navy and Marine Corps Industrial Control Systems Monitoring Stations*	1 Apr 2015
FC 1-300-09N	*Navy and Marine Corps Design Procedures*	1 May 2014, Change 2, 21 Aug 2015
ALNAV 068/09	SECNAV Energy Message to the Fleet	30 Oct 2009
Other Federal Instructions		
DoDI 851001	*Risk Management Framework for DoD Information Technology*	12 Mar 2014
EISA 2007	Energy Independence and Security Act of 2007 Public Law 110-140 HR 6	2007
VA 48 14 00	*Solar Energy Electrical Power Generation System*	1 Jan 2013
Executive Order 13693	*Planning for Federal Sustainability in the Next Decade;* *Federal Register,* Volume 80 Issue 114	19 Mar 2015
Department of Defense	*Strategic Sustainability Performance Plan*	2015
Department of Energy	*The Smart Grid: An Introduction*	2008
DUSD I&E	Department of Defense Sustainable Buildings Policy	10 Nov 2013
DUSD I&E	Financing of Renewable Energy Projects Policy	9 Nov 2012
DUSD I&E	Utilities Metering Policy	16 Apr 2013
SECNAVINST 41013	Department of the Navy Energy Program for Security and Independence Roles and Responsibilities	3 Feb2012
Unified Facilities Criteria and Uniform Facility Guideline Specifications		
UFC 3-400-02	*Design: Engineering Weather Data*	28 Feb2003
UFC 3-440-01	*Facility Scale Renewable Energy Systems*	1 Jul 2015
UFC 3-440-05N	*Tropical Engineering* with Changes 1-2	28 Nov 2006
UFC 3-470-01	*Lonworks (R) Utility Monitoring and Control System*	1 May 2012
UFC 3-501-01	*Electrical Engineering*	6 Oct 2015
UFC 3-510-01	*Foreign Voltages and Frequencies Guide*	1 Mar 2005
UFC 3-520-01	*Interior Electrical Systems*	6 Oct 2015
UFC 3-520-05	*Stationary Battery Areas*	11 Sept 2015
UFC 3-540-01	*Engine-Driven Generator Systems for Backup Power Applications*	1 Aug 2014

Table 1-1. Microgrid Reference Guide		
UFC 3-550-01	*Exterior Electrical Power Distribution*	1 Jul 2012
UFC 3-575-01	*Lightning and Static Electricity Protection Systems*	1 Jul 2012
UFC 4-025-01	*Security Engineering: Waterfront Security*	1 Nov 2012
UFGS 26 00 0000 20	*Basic Electrical Materials and Methods*	Jul 2006
UFGS 26 05 4800 10	*Seismic Protection for Electrical Equipment*	Oct 2007
UFGS 26 08 00	*Apparatus Inspection and Testing*	Aug 2008
UFGS 26 11 1300 20	*Primary Unit Substations*	Apr 2007
UFGS 26 11 16	*Secondary Unit Substations*	Feb 2010
UFGS 26 12 1910	*Three-Phase Pad-Mounted Transformers*	Feb 2012
UFGS 26 13 00	SF6/*High-Firepoint Fluids Insulated Pad-Mounted Switchgear*	Nov 2014
UFGS 26 13 01	*Pad-Mounted Dead-Front Air Insulated Switchgear*	Aug 2013
UFGS 26 20 00	*Interior Distribution System*	Feb 2014
UFGS 26 23 00	*Low Voltage Switchgear*	May 2015
UFGS 26 24 13	*Switchboards*	May 2015
UFGS 26 27 14.00 20	*Electricity Metering*	Feb 2011
UFGS 26 28 01.00 10	*Coordinated Power System Protection*	Oct 2007
UFGS 26 31 00	*Solar Photovoltaic (PV) Components*	May 2015
UFGS 26 32 13.00 20	*Single Operation Generator Sets*	Apr 2007
UFGS 26 36 23.00 20	*Automatic Transfer Switches*	Apr 2006
UFGS 26 41 00	*Lightning Protection System*	Nov 2013
National Codes and Standards		
NFPA 70	National Electrical Code	2014
IEEE Standard 1547	*Interconnection of Distributed Resources with Electric Power Systems*	12 Jun 2003
IEEE Standard 2030	*Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System*	10 Sept 2011
Cybersecurity References		
NIST 800-82	*Guide to Industrial Control System (ICS) Security*	June 2011
NIST 800-53, App 1	*Security Controls, Enhancements, and Supplemental Guidance*	April 2013
DoDI 8500.2	*DoD Information Assurance (IA) Certification and Accreditation Process*	6 Feb 2003
UFC 4-010-06	*Cybersecurity of Facility Related Control Systems*	19 Sept 2016
Committee on National Security Systems Instruction 1253 Attachment I	ICS Security Overlay Vendor and DoD Security Guides for Network, OS, Application, and similar	27 Aug 2013

Table 1-1. Microgrid Reference Guide

Additional Resources		
Whole Building Design Guides	Net Zero Energy Buildings	16 Dec 2014
Lincoln Laboratory: Massachusetts Institute of Technology Technical Report 1164	*Microgrid Study: Energy Security for DoD Installations*	18 Jun 2012

DoD = Department of Defense
DoDI = Department of Defense Instruction
DUSD I&E = Dep. Under Secretary of Defense, Installations and Environment
FC = Facilities Criteria
IEEE = Institute of Electrical and Electronics Engineers
NFPA = National Fire Protection Association
NIST = National Institute of Standards and Technology
SECNAV = Secretary of the Navy
SECNAVINST = Secretary of the Navy Instruction
UFGS = Uniform Facility Guideline Specifications
UFC = Unified Facilities Criteria
VA = Department of Veterans Affairs

2 Microgrid Overview and General Knowledge

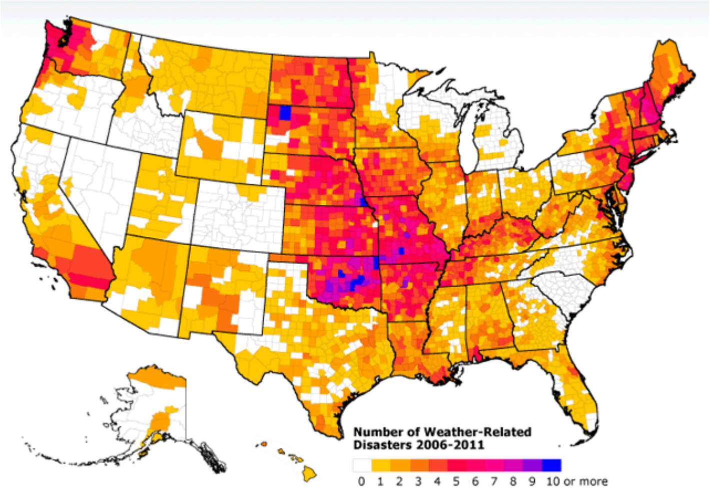
2.1 Background

U.S. military installations face unique challenges when it comes to maintaining the electrical support necessary to safeguard their mission-critical operations:

1. Aging infrastructure, much of which is approaching 100 years old
2. Increasing frequency of natural disasters as a result of climate change
3. Increasing frequency of cyber-attacks, including nation state attacks

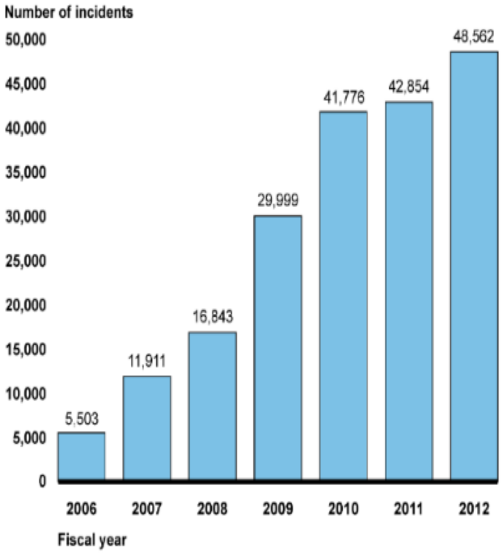
In August 2013, the White House Council of Economic Advisers and the U.S. Department of Energy (DOE) released a report on the resiliency of electric grids during natural disasters. In the 10 years prior to the report, utility grid outages due to weather cost the country between $18 billion and $33 billion annually. An average of 68 incidents per year affected at least 50,000 people (DOE, 2013). In extreme cases, the power outages are the result of incidents so severe that areas are declared federal disaster areas. Figure 2-1 illustrates potential “hot spots” throughout the United States.

Also over the past decade, the U.S. Government Accountability Office (GAO) reports that the number of cyber-attack incidents has escalated to nearly 50,000 per year, as shown on Figure 2-2 (GAO, 2013).



Source: Environment America, 2015

Figure 2-1. U.S. Counties Federally Declared Disaster Areas due to Extreme Weather, 2006 - 2011



Source: GAO, 2013

Figure 2-2. Growth of Utility Incidents Reported, 2006 - 2012

Implementation of a microgrid is a strategy by which a military installation may separate from the grid during an extended outage event and control its own ability to maintain mission integrity.

2.2 What is a Microgrid?

> A microgrid is an Integrated System of electricity generation, distribution infrastructure, and energy storage (as needed) to maintain power while disconnected from commercial grids. (Lindsey, 2012)

Microgrids are distinguished from other grid-modernization efforts, such as smart grids and virtual power plants (VPPs), by two unique attributes:

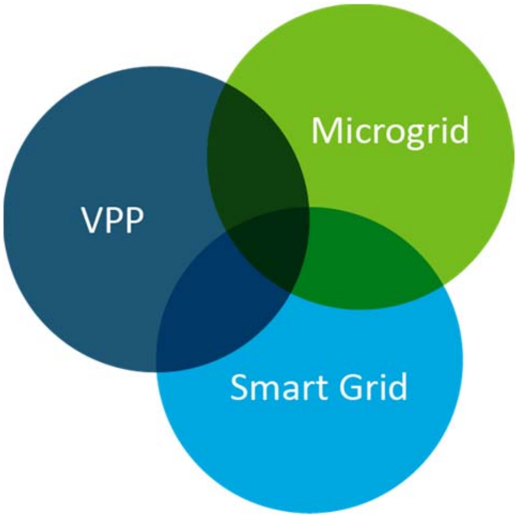
1. A microgrid is a collection of generation and load centers **with fixed limits**.
2. A microgrid can operate in both *grid-connected* and *isolated* (**island**) modes.

Smart grid technology typically refers to the use of intelligent communication and control systems to optimize and coordinate energy devices, such as:

- Energy-generating resources like engines, turbines, solar, and wind power
- Energy-storage devices like batteries, water reservoirs, or compressed-gas storage devices
- Energy-users like heating, ventilation, and air conditioning equipment, process equipment, lighting, appliances, factories, and buildings

Microgrid vs. Smart Grid. Smart grids do not necessarily have a fixed boundary and are not associated with island conditions. They are designed for normal conditions, not emergency conditions. A microgrid should be “smart,” but a smart grid is not always a microgrid. A smart grid does not require a local generation or energy source to function; a microgrid does because it must function in the absence of grid power.

Virtual Power Plant. VPP typically refers to shared metering arrangements for economic purposes. VPPs often provide the automation and control features required to remotely and automatically dispatch and optimize generation, demand response, and storage, but they do not operate within fixed boundaries and they are not designed to operate during emergency conditions. VPPs may contain elements of a microgrid, but the existence of a VPP does not necessarily imply a microgrid, although a microgrid may include features of a VPP.



An optimal situation may be the intersection where a microgrid operates as a smart grid and as part of a VPP.

An installation may have multiple microgrids existing simultaneously. Figure 2-3 shows a conceptual site electrical distribution system where the outer dotted line (B) identifies a potential “site microgrid.” Clearly defining the microgrid boundary is one of the first steps in the design process. The connection to the utility grid is illustrated in the upper left of Figure 2-3 (Point C). Where a microgrid connects to a commercial electric utility is known as the point of common coupling (PCC). Point D, on the right side of the potential microgrid, is a distribution line going to unidentified use at an airfield; this is not allowed in a microgrid. Microgrids require defined physical boundaries, so an extension crossing the boundary would not be allowed. However, if the extension has an automated isolation device installed at the boundary crossing, it could be allowed. In any case, where the microgrid design isolates downstream uses, the design team must include an investigation of downstream power distribution as part of the microgrid analysis.

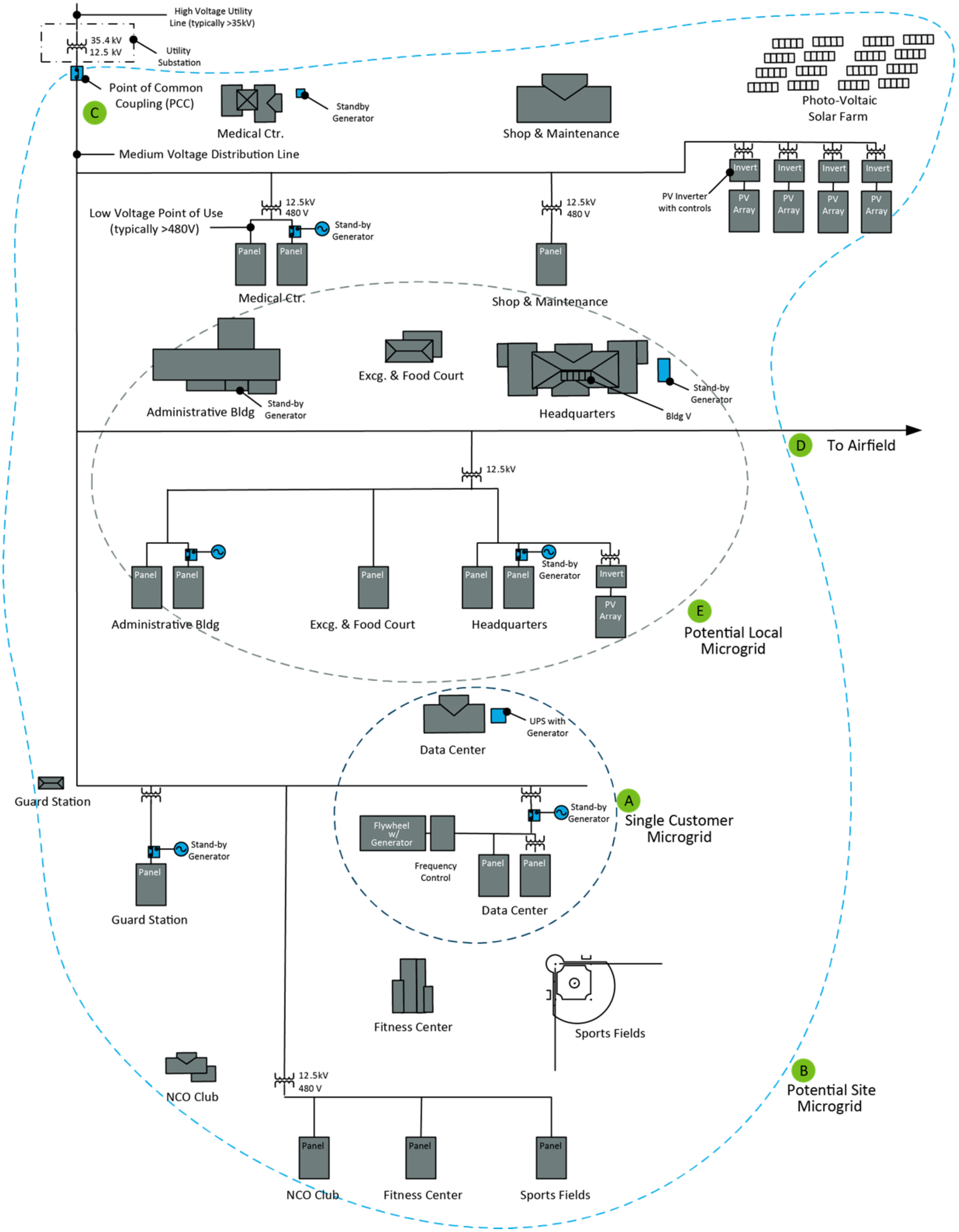


Figure 2-3. Example of an Installation with Multiple Microgrids

Figure 2-3 illustrates a single-customer microgrid (Point A) and the potential multi-customer local microgrid (Point E) in the center. Both operate in defined boundaries with automated switches to isolate the microgrid when grid power is not available. As shown on Figure 2-3, when the local microgrid is operating, it optimizes the two emergency generators and integrates renewable energy. When a system is more complex, attention must be given to the possibility of a microgrid design affecting downstream distribution.

2.3 Benefits and Capabilities

A microgrid's primary benefit is its ability, as a bounded system, to disconnect from the commercial grid during an emergency so that energy users (loads) within the boundary may share the distributed energy resources (DERs) that are also within the boundary. This allows the closed system to be optimized when in island mode; it also allows renewable resources to be enabled when the grid is down. Per the National Electric Code, energy sources, including renewable energy, cannot be connected to a non-functioning grid. A bounded system's point of connection to a grid is called the PCC or Interconnection (there may be more than one). Without a defined boundary, it is difficult to guarantee the microgrid will totally disconnect from the grid when the grid is down. If the bounded microgrid is not totally disconnected from the down grid, any generation, including emergency generators or renewable energy sources, must be shut down or isolated because they could back-feed power to the grid and present a hazard to utility workers who are working on what they thought was a de-energized system.

Microgrids are primarily designed to respond to external grid failure. If failure occurs within a microgrid, systems such as emergency generators or specifically designed renewable resources may continue operating by isolating and forming their own sub-microgrid systems. These systems may become the initial reference synchronization signal as the microgrid is formed.

When not in island mode, microgrid resources and systems provide smart grid and VPP capability. The smart grid encompasses the technology that enables intelligent control devices to integrate with wind turbines, solar arrays, batteries, generators, loads, and other actors associated with the grid.

Figure 2-4 shows a typical electrical one-line diagram of an installation's subsection. The subsection consists of three buildings (two of which have single-customer emergency generators) and a renewable energy resource associated with one building (a photovoltaic [PV] array). The subsection is bounded and can be electrically isolated by opening a device at the 12-kilovolt (kV)/480-Volt (V) transformer. By modifying the control system, this grid subsection becomes a candidate to be a microgrid.

A microgrid with integrated monitoring and controls could be beneficial in the following applications:

- Renewable energy integration: Reduced environmental impacts, energy independence, cost savings, compliance with Executive Order (EO) 13693, *Planning for Federal Sustainability in the Next Decade*
- Demand reduction and peak shaving: Cost savings, operating within generation constraints
- Energy use reduction: Cost savings
- Improved system operation: Resource efficiency

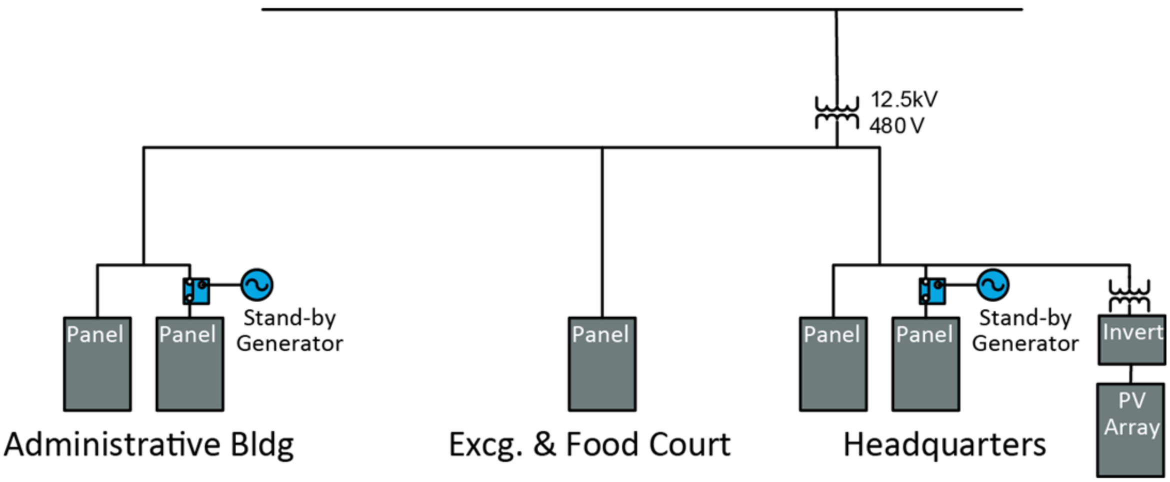


Figure 2-4. Subsection of Larger Microgrid and Candidate to become a Microgrid

Figure 2-5 shows the same subsection as a microgrid, but switches and control devices have been added. Device 1 isolates the subsection from the sitewide distribution system. Device 4 disconnects the exchange and food court, which are not critical. Devices 2, 3, 5, and 6 provide flexibility to disconnect or connect selected areas of the administration and headquarters buildings if sufficient microgrid energy is available. The PV array inverter automatically disconnects upon power failure according to its normal protocol. As part of a microgrid the inverter system is modified, the microgrid controller now manages the PV array with an inverter controller (Device 7) and reconnects as soon as microgrid power is restored. By forming the microgrid, depending on details, the generators may be better optimized to backup each other and use renewable energy to reduce fuel use during the grid outage. However, in practice this solution is typically not practical. Generators need to have sufficient excess capacity to share their loads and the new control system needs to be capable of enabling load sharing. While simple in concept, coordination among tenants can be challenging for multiple reasons to include issues around funding sources. In addition, most DON generators are not designed for such service because of insufficient capacity, emissions ratings, or fuel capacity; these generators would need to be replaced or upgraded. Therefore, the concept shown on Figure 2-5 is appealing for its simplicity and could be an option to consider in a specific situation; however, it may not always be the best solution.

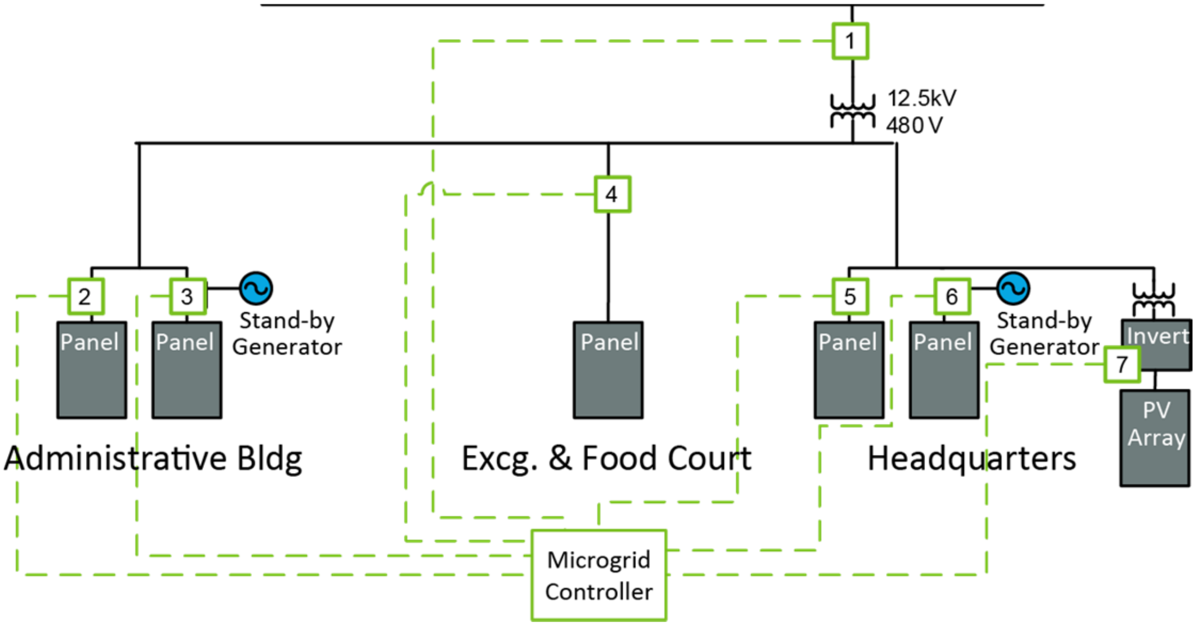


Figure 2-5. Subsection as a Standalone Microgrid

It should be noted that the original point of power failure could be on the base, within the boundaries of the microgrid. Generally, the traditional microgrid control system would not form a microgrid in the event of an onsite failure because the grid would still be functional. However, sub-microgrid systems may be formed and emergency generators (single-customer microgrids) should engage. Designs for military applications need to consider all viable failure modes.

For purposes of this guide, it is assumed that the microgrid's primary purpose is to provide enhanced energy security to critical military infrastructure during extended periods of grid failure (energy surety) and to support optimal integration of distributed generation and renewable resources.

2.4 Challenges and System Impacts

Early consideration should be given to the condition index of the existing electrical system. The Facility Condition Index and Condition Index/Condition Rating should be reviewed as part of the initial assessment. This information may be requested from Commander, Navy Installations Command (CNIC).

A challenge related to the microgrid design is electrical system protection. A pre-microgrid design includes protective devices that can identify faults and nearly instantaneously isolate the faulty circuit feeder to prevent damage to the remainder of the circuit and to the system as a whole. These devices often function by detecting high current levels associated with a fault. When connected to the grid, the utility system is capable of delivering the energy necessary to produce the high current. In microgrid mode, the distributed generators may not have capacity to provide enough energy to produce a sufficiently large current spike that could be detected by the protective equipment; the fault could go undetected and cause system damage. The onsite grid designs and protection equipment that were adequate before a microgrid was implemented may not offer adequate fault protection and may need to be revised. Analysis of the system protection design will include system simulation modeling prior to final design and construction. Protective device coordination studies will be performed as part of design and updated during construction.

An additional challenge is synchronization. As soon as the primary grid fails, DERs begin to come on line. Many of an installation's DERs will be standard emergency generators that are associated with specific loads. The DERs will operate autonomously, as they normally do, and will tend to be out of phase with each other. When the interconnection point is opened and the installation's connection to the grid is severed, the DERs must synchronize before forming a microgrid. DERs must be "in phase" as they are connected (this is also true of the renewable resources that are added to the microgrid). A reference frequency is selected from among the DERs and all other DERs align to the reference. The synchronization process repeats when the grid comes back on line and the microgrid prepares to reconnect at the PCC. In this case, however, the microgrid DERs (in unison) use the utility frequency as their reference and synchronize to the utility.

The third challenge is power quality. Because microgrids are smaller, they tend to be more vulnerable to transients. Transients, which could result from normal operations such as switching, renewable energy spikes (up or down), and transformer inrush currents, must be managed to avoid equipment damage. Motor starting and other sources of reactive power are a concern. These power quality issues are dynamic and generally require modeling as part of the design process.

Finally, the new system design should be carefully coordinated with any existing site facility monitoring and control system. The Owner/Operator of the existing system should be involved from the very start of design to ensure that the systems communicate with each other and training, operations, and maintenance requirements are understood and well planned.

2.5 Different Microgrid Applications

Microgrids are generally identified with respect to their features, characteristics, and purpose. This includes how they are operated and what types of fuel or energy resources they need. The primary purpose may be integrating renewable energy, community resiliency, or other driver, such as cost reduction. Although there are no clear definitions regarding microgrid subcategories, several applications or types of microgrids are discussed below:

- **Grid-connected or Continuously Islanded.** This determination is generally a first distinction (that is, will the microgrid ever be connected to a larger grid, or is it always stand-alone). For practical purposes, any continuously islanded system is a microgrid (unless it is called a utility). If connected to a larger grid, by the definition above, the microgrid must be capable of islanding. There cannot be a non-islanding microgrid. In remote locations with no available grid connection, distributed generation resources may be integrated to form a microgrid to improve efficiency, reduce cost, and improve reliability.
- **Size or Complexity**. These are relative terms with no specific quantitative definition. A system could be large, yet simple, such as a single customer powered by a single generator. Alternatively, it may be small and yet have multiple distributed resources and multiple different loads. A common simple system like an emergency backup power generator that supports a single building is often referred to as a single-customer microgrid or, occasionally, as a nano-grid. Single-customer microgrids are simple and easy to understand.
- **Renewable Microgrid**: The term “renewable microgrid” describes a system where the primary purpose of the microgrid may be to integrate renewable energy, particularly during power outage. All microgrids should be designed to maximize renewable energy to the extent possible. Although renewables are not a microgrid requirement, the use of renewable energy during power outage does require some type of microgrid formation (at the very least a single-customer microgrid).

  EO 13693 sets high standards for the use of renewable energy in federal buildings; 30 percent of the electrical energy consumed by federal agencies must be renewable by fiscal year 2025 and each year thereafter (note the goal is an aggregate and does not apply to each building individually). The EO mandates the use of renewable energy. Once the renewable energy is available, microgrids are an effective means of using renewable energy during grid power outage situations.

  By effectively using microgrid resources (hardware, control systems, and software), the penetration of renewable energy may be increased during normal operation.
- **Community Resiliency Microgrids**: Community resiliency microgrids are intended to provide community resiliency, and are typically funded with public money. For the past few years, community resiliency microgrids have been tracked by some information analysis organizations as an independent category. Community microgrids may have islanding issues if they are not carefully planned with all stakeholders; this type of system could risk disconnecting downstream loads when in island mode. Installation microgrids are effectively a community resiliency microgrid where the community is a military site.
- **VPP Microgrid**: A microgrid may be formed as part of a VPP, disconnecting as needed from the grid to reduce demand on the main grid. The objective is to reduce future capital investment of the utility; the microgrid owner should receive a cost benefit. VPPs are not necessarily bounded, but may have a microgrid operating as a subsystem within the VPP. A remote base with no available utility may be a Continuously Islanded Microgrid and operate as a VPP; thus, it is a hybrid.
- **Hybrid Microgrid**: Larger, more complex microgrid systems often become hybrid microgrids; they have a combination of objectives, may use a blend of energy sources, and may have a variety of features. A microgrid built for emergency backup can island to support the grid, integrate renewable energy, correct the power factor, use battery power, and be smart.

2.6 Typical Microgrid System Components

2.6.1 Critical Loads and Buildings

Mission-critical loads for all installations are identified as part of the Mission Assurance and Continuity of Operations Plan. Much of the information regarding loads and buildings will be classified; before embarking on a microgrid design, the installation's critical loads must be determined. These loads may be located on the main installation or off installation in a geographically separated area.

Microgrid designs, as opposed to typical emergency generator designs, focus on longer term outages of days and weeks. During a microgrid assessment, the microgrid design team will need to verify the services and functions that are provided by each load determined to be critical. Once the mission-critical loads have been identified, the interrelationships and dependencies of those loads should be confirmed.

Establishing microgrid capability is not intended to diminish the underlying system's capability. Existing emergency generators should remain in place to sustain the mission should the microgrid fail. The microgrid may *build upon* existing capability or *modify* existing capability; the strategy is a design and mission judgment decision.

During the early phases of project assessment, critical buildings and loads are identified based on DON criteria and Base mission. The Base determines the final building classification with respect to operation and mission. In the microgrid design process, a second assessment is needed to classify the critical loads as they pertain to the microgrid. Critical loads should be supported—however, not all critical loads are necessary for microgrid operation and some non-critical loads may be essential for microgrid operation. The microgrid design process includes determining the following classification for each asset as it relates to the microgrid operation:

- **Microgrid Essential**. These buildings or assets are required to support the microgrid as designed, and could include buildings with significant backup generators that could support the microgrid (if they are capable), distribution-level PV arrays, or other supplemental resources.
- **Microgrid Supported**. These buildings or assets are connected to the microgrid and their infrastructure is designed such that their loads are served by the microgrid under most conditions. These facilities may or may not have generators; if they do, the generators are not required to be operating to keep the microgrid stable.
- **Microgrid Discretionary**. These buildings are able to connect to the microgrid, but they can also be isolated at the discretion of the installation commander. Ideally, these buildings have automated switches for connecting/disconnecting from the microgrid, but this could be a manual function that serves the same purpose.
- **Non-microgrid**. These buildings are outside the microgrid service and are automatically isolated before forming the microgrid.

The above definitions do not define the importance of a particular building or resource. Assets that are not critical to the mission may be essential to the design of the microgrid. Base leadership and stakeholders are ultimately responsible to determine which loads are critical and how they will be supported. The microgrid design team determines what resources are essential to the microgrid operation.

2.6.2 Existing Equipment and New Equipment Requirements

Integrating renewable microgrid technology into a site electrical system is significantly different from conventional energy programs. Microgrid projects tend to involve more than replacing equipment with newer more efficient versions of the same equipment. Consequently, microgrid projects require sophisticated analysis.

The capacity of the incumbent site equipment, primarily emergency generators stationed at critical loads, and existing renewable energy resources must be evaluated. The microgrid could provide additional stationary generators and more renewable energy to provide sufficient generation capacity when isolated from the commercial power grid. To help manage system transients and store energy, batteries may be incorporated. Control systems will be enhanced. Medium-voltage and low-voltage connect/disconnect devices (such as switches) will be used to quickly reconfigure the system, and specialty devices will be employed to synchronize the various components to produce stable power (Figure 2-6).

In addition to the above, various combinations of batteries, rotating generator reserves, combined heat and power systems, and building/process control systems could be used to provide design solution options.

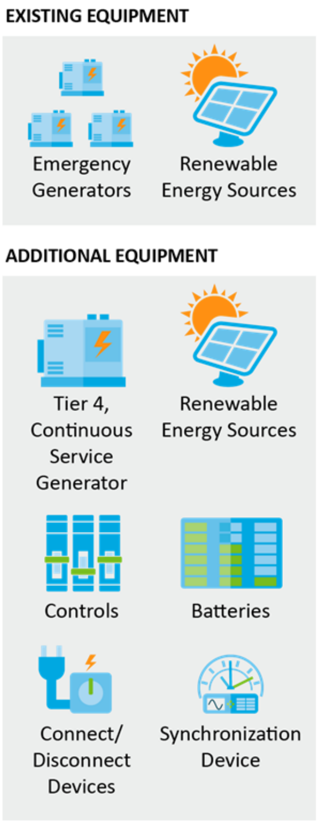


Figure 2-6. Possible Microgrid Equipment

2.7 Commercial Utility Interconnection Agreements, Interaction, and Cooperation

A properly designed microgrid can become a resource during normal operations to self-manage power consumption and cost independent of the commercial utility provider. Installation personnel can also use the microgrid to negotiate alternative rate structures with the utility in exchange for cooperation in managing the grid loads. Some commercial utilities have significant limitations with respect to contract agreements; for example, some will not allow power export, while others want access to power. Early discussion with the commercial power provider should be part of the preliminary background data gathering. Once changes are incorporated in the commercial utility agreements, the installation can autonomously take the following actions:

- **Control of Demand Charges**. There are multiple technologies that may be used for electrical demand reduction, including load management, energy storage, and the use of renewable and non-renewable energy sources. Microgrid designers should consider how the design of a microgrid could be used to reduce demand. The possible integration with a solar energy system can be an example. Solar energy primarily is seen as a resource for energy reduction. Although demand commonly peaks during the day when solar energy is available, cloud cover causes substantial, random, decreases in solar power. The probability of 100 percent solar availability is low. Although solar power may have some demand reduction potential, its full potential is seldom realized. However, by using microgrid batteries and/or generators, the solar system may be backed up for purposes of demand management with the microgrid resources. (Note: Generators must be permitted for emergency and non-emergency use.)

- **Power Factor Correction**. Electrical systems include loads that do not act as simple resistance. More complex energy uses, such as motors, may cause phase misalignment of voltage and current. Apparent power does not equal true power. The misalignment, called Reactive Power is measured in units of Volt-amp reactive. Utilities may charge the installation for a power factor that is less than their established rate structure (typically 0.90 leading or lagging). Microgrid designs may typically include control systems to correct power factor.

- **Contract Revision**. In cooperation with the local utility and by negotiating a new contract, the installation can take additional actions. Within the United States, utilities are highly regulated and do not have unlimited freedom to negotiate rates. However, they frequently have published alternative rate schedules that provide discounts to customers willing to modify consumption to help the utility meet its objectives, such as the following:

  - **On-Call Demand Reduction** is an agreement in which the utility customer agrees to reduce its load upon request and receives a reduced rate structure in return. The number of times per month for a reduction request is usually limited and the duration and amount of the reduction is limited. The microgrid generator resources (if permitted for non-emergency use) may be used to offset the load, and control systems can be used to shed or manage the load.

  - **Fixed Reduction on Preset Schedule** is an agreement in which the utility customer agrees to reduce its load by a fixed amount for a set time every day. The microgrid generator resources (if permitted for non-emergency use) may be used to offset the load, and control systems can be used to shed or manage the load.

SECTION 3

3Site Evaluation and Feasibility Determination

3.1 Engineering Analysis

To determine if a microgrid is a viable solution, the local NAVFAC component and the supported commands need to understand the installation's existing goals, objectives, and system specifics. Microgrids should be evaluated in in the context of the installation's overall goals and objectives as a cost-effective solution when coupled with mission resiliency and reduced reliance on outside commercial power providers. The evaluation should include historical and projected future reliability of the local commercial power provider. This section focuses on planning, specifically the processes, methods, tools, and options available to NAVFAC, in performing site evaluations and determining the feasibility of installing a microgrid.

3.1.1 Performance Goals and Objectives

As previously discussed, the assumed primary function of a military microgrid is energy surety and protection of mission viability. Additional goals may include carbon dioxide reduction, renewable energy integration, and energy cost reduction.

3.1.2 Cost/Benefit Analysis

Two approaches are recommended as a starting point for a microgrid cost/benefit analysis.

1. If the energy surety case is strong based on the need to protect the mission from possible extended grid failure, establish a baseline microgrid design that consists primarily of generators. Using one or a few centrally located generators rated for continuous service will typically have a lower cost than attempting to add an additional backup generator in the same location as every emergency generator (see Figure 3-1).

   Above the baseline cost, add technology to enhance the microgrid and reduce **operating** cost, such as smart grid technology that includes advanced measurement and two-way communication between energy user and producer[1], VPP participation (which involves cooperation with others in the same energy market), and renewable energy. Each enhancement should be evaluated for its cost/benefit based on payback and return on investment (ROI). Because enhancements add marginal cost, their capital and operating costs will be relatively low. ROI for these marginal additions may be relatively good.

   Figure 3-1 shows the microgrid shown on Figure 2-5 with an additional generator and fuel storage tank. In this case, mission security is a primary driver. The new generator is designed to operate during periods of extended outage and has a new fuel tank to support the objective. If the grid fails, two approaches may be taken:

   1) Open Device 1 and form a microgrid with the new continuous duty-rated generator providing power. The existing backup generators act as backup.

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[1] See the U.S. Department of Energy's *The Smart Grid: An Introduction* (2008). http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages%281%29.pdf

2) The existing backup generators respond normally and after a predetermined period, the microgrid forms and the backup generators become backup to the new continuous-service unit.

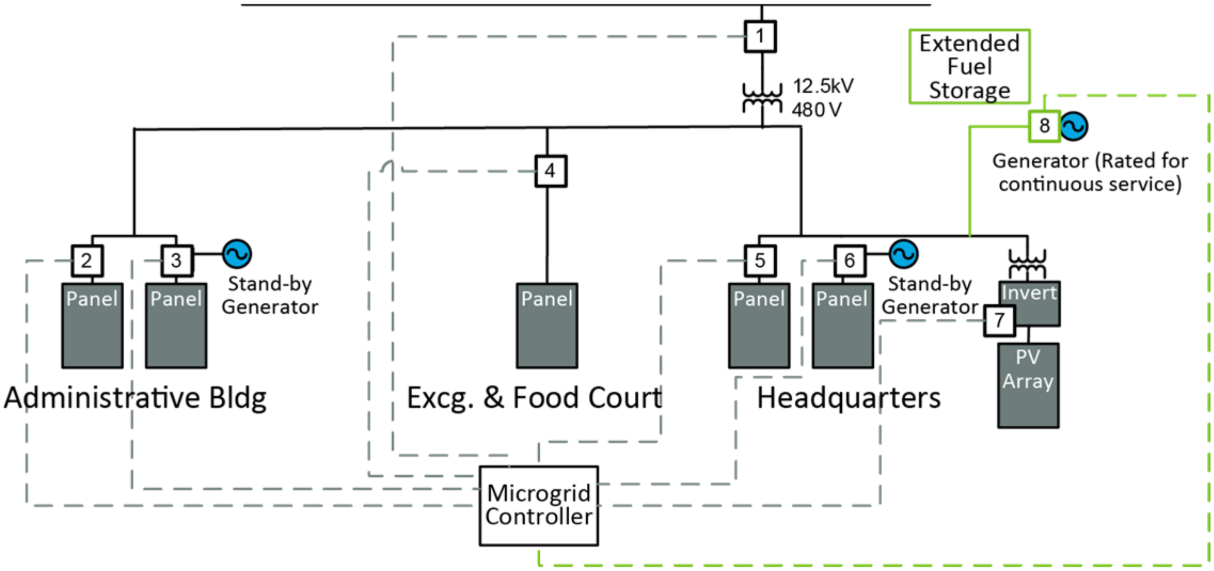


Figure 3-1. Local Microgrid with Continuous Service Capability

2. If the case for adding renewable energy is strong, the addition of an energy storage device (for example, batteries or flywheel) can lend stability to the renewable output and substantially increase safe use of renewable sources at high levels (this may be done without a microgrid). In this case, the battery or flywheel is relatively small and the primary objective is transient system response of renewable output swings associated with clouds or wind speed changes (Figure 3-2).

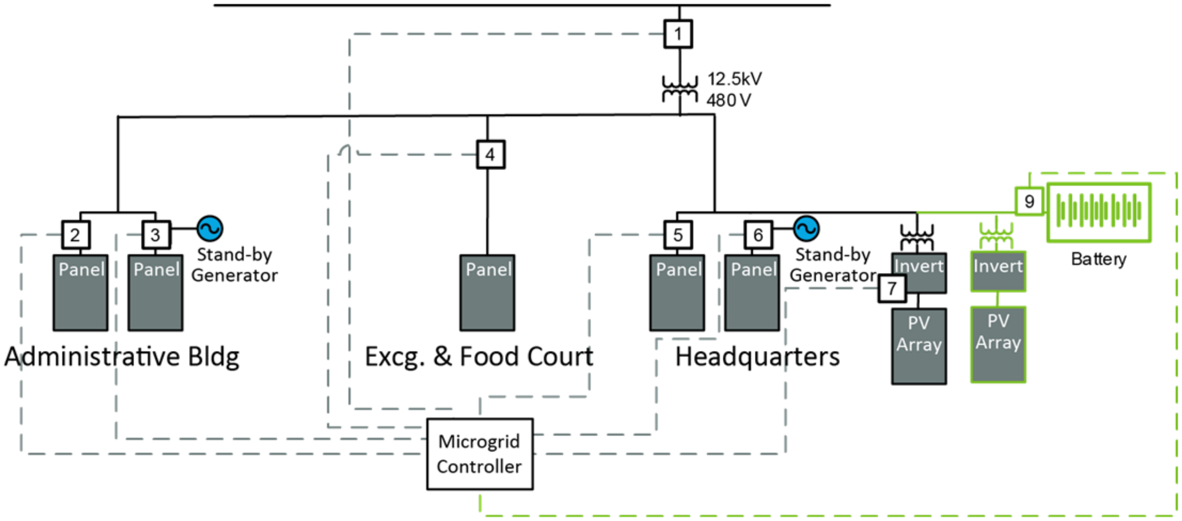


Figure 3-2. Local Microgrid with Battery Dampener for Renewables

Figure 3-2 shows the microgrid of Figure 2-5 with the addition of battery storage at the PV array. In this case, higher penetration of renewable energy is an objective and is accomplished by using the battery to buffer PV variability. Renewable energy resources, particularly wind and PV solar, suffer from rapid fluctuations in output, which cause electrical instability. By adding battery storage as a dampener, renewable energy use may be increased. Generators may also be used as a spinning reserve to respond to drops in renewable energy (but generators consume fuel when they are in spinning reserve mode; see the alternative illustrated on Figure 3-3). In this case, renewable penetration and system stability drive the argument for energy storage, not financial concerns.

Future potential uses of energy storage include energy arbitrage, participation in demand response programs, and load shifting.

If one of the above two arguments is successful, the case for a hybrid solution may have good financial merit. Only the added marginal cost for the hybrid system is considered in the financial analysis.

Figure 3-3 shows the microgrid of Figure 2-5 with the addition of a hybrid generator and energy storage system. The system is intended for use when renewable energy production coincides with the site's peak demand, which is a common occurrence with solar energy. The energy storage system is designed and sized to bridge short periods of renewable energy decline (for example 0.25 to 1 hour, optimized based on statistical analysis). The energy storage system is backed up by demand-reduction strategies and ultimately the Tier 4 generator. The generator is not operated in spinning reserve mode, so it does not consume fuel when not needed. However, the generator may be started quickly and put in spinning reserve mode if needed. During the delay, the battery supports the load.

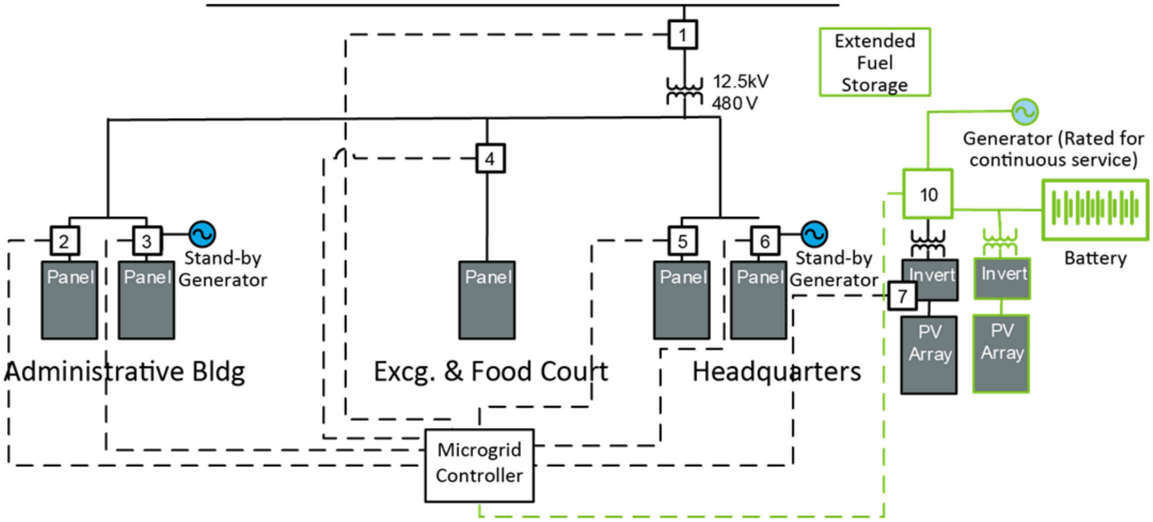


Figure 3-3. Local Microgrid with integrated Generator/Battery Management System

The systems illustrated on Figures 3-1 and 3-2 are optional base-case solutions for extended islanding duration and high renewable energy penetration, respectively. The hybrid solution (Figure 3-3) accomplishes both and has an added benefit of potentially reducing utility demand charges.

The financial merit of renewable energy is often based on the levelized cost of electricity (LCOE), which converts the renewable energy capital and operating cost for any location to an equivalent average cost of energy (cost per kilowatt-hour [kWh]) over the life of the project. LCOE models include variables such as climate and availability of solar energy. The analysis is suitable for small businesses and residential applications where the utility bill is a simple energy bill. Rarely do utilities have specific classifications for military bases; because of their size and amount of energy use, military bases are generally treated as industrial clients and typically pay a lower energy cost and potentially a significant "demand" charge. The benefit of the hybrid system is the ability to manage demand charges with very high reliability. In some cases, demand-reduction cost savings may equal energy savings.

3.1.3 Constructability and Site Constraints

Most of the microgrid technology implementation will consist of installing controls, adding switches, and changing operational procedures. Consequently, there are few building code issues with microgrids. The following site constraints or restrictions should be considered:

1. Site space and environmental permitting issues associated with one or more microgrid generator and battery energy-storage locations: often it is attractive to centralize any new generating capacity

and to use larger generators because cost per capacity is lower. If environmental permits allow, operating generators (with suitable emissions controls) during non-emergency situations can trigger options for cost reduction.

2. Site space, permit, and climate factors associated with renewable energy: this includes site operational issues, such as wind turbine restrictions.
3. Relationship with local electric utility and options available to modify the service contract: this includes options available to cost share (capital cost or maintenance cost).

3.1.4 Performance Metrics

Microgrids have the following primary performance metrics:

1. Number and strength of Design Basis Threats (DBTs) the system will withstand, including cyber threats
2. Critical infrastructure support capability and reliability
3. Islanding duration
4. Response time
5. Power quality and reliability when in island mode

Early in the design, the primary concern is to demonstrate that all mission-critical systems are backed up appropriately in the event of extended grid failure and that failure of a single component, such as a backup generator, does not compromise the mission.

As options are developed, they are compared based on the above primary performance metrics. When evaluating options, if the above primary performance metrics are approximately equal, financial and environmental performance may be considered.

Microgrids (more appropriately the equipment available by virtue of the microgrid) may contribute to operational cost savings and could have secondary financial performance metrics:

- Cost of energy ($/kWh), measured as LCOE
- Demand charges ($/kilowatt [kW])
- Power factor, measured relative to 1.00
- Rate agreement changes ($/year savings)

In addition to a financial benefit, the microgrid equipment may be used to increase renewable energy penetration and thus reduce the installation’s carbon footprint.

3.2 Identifying Requirements for the Microgrid

The microgrid design may include elements of a smart grid and VPP, but the primary purpose of a microgrid is to respond effectively to grid failure by going into island mode. The design team will conduct stakeholder meetings to establish management objectives and define DBTs.

Management objectives may include targets for renewable energy integration and penetration. Discussions of DBTs will include establishing targets for duration of operation in island mode.

3.2.1 Background Information

Before beginning the site evaluation and feasibility determination, NAVFAC and the site Utility Engineer need to gather available background information. Background information includes the following:

- Brief general description of the installation (site), including a discussion of topics relevant to a microgrid, particularly future plans for the installation.

  - Map or drawing of the region
  - Site constraints, including building permits and construction limitations
  - Illustrative photographs of the site
- Site data
  - Installation Master Plan
  - Utility Maps, drawings, and infrastructure information
  - Mission Dependency Index: Rates each facility on the site depending on criticality of function (using a scale of 1 to 100)
  - Electrical rate schedule
  - Existing electrical site load and load profile
  - Site drawings with significant buildings and features identified
  - Weather data
  - Site electrical load information (by buildings and equipment)
    - Advanced metering infrastructure (AMI) data, if available
    - Descriptive information
- Available reports, energy audits, and studies
- Available historical data and studies regarding outages and potential natural disasters
- Waterfront or Shipyard mission-critical systems
- Load shedding and utility restoration plans
- Generator List
- Installation Development Plan
- Priority Facility List

3.2.2 Critical Loads

During the conceptual design phase, potential **critical loads** need to be identified. This will include discussion with all site stakeholder groups. At military installations, buildings and loads critical to the mission are well defined, although in some cases the function may be classified. The design team needs to work with the affected Command to define requirements. The challenge is often defining dependencies. Consequently, as critical loads are identified, the design team needs to identify supporting systems that, if they fail, will ultimately lead to a failure of an identified mission-critical system.

Identification and prioritizing of critical loads begins with discussion of the mission. In a structured approach, the design team would facilitate discussions focused on the mission-critical equipment and systems. Next, the design team and stakeholders would identify the buildings and systems

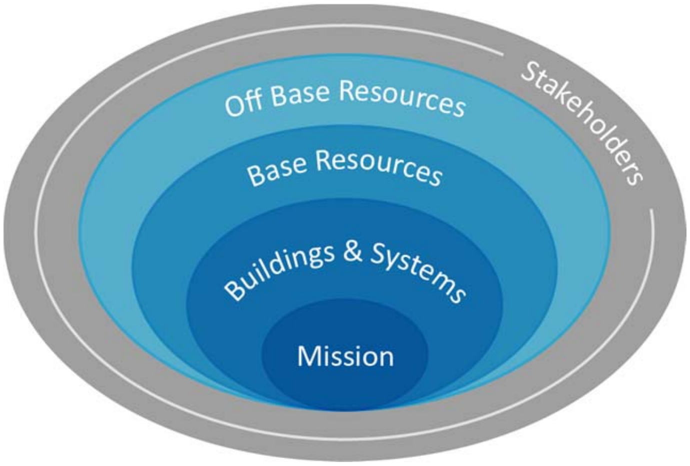


Figure 3-4. Expanding Domain of Critical Infrastructure

required to support the mission-critical elements, followed by identifying the on-base resources needed to support mission-critical elements and the off-base resources needed to support the critical on-base resources. Eventually, all the stakeholders involved in the ever-expanding potential microgrid system become stakeholders of the microgrid (Figure 3-4).

Identifying critical assets and systems is a repetitive and expansionary process that must be controlled. The design team will need to continuously challenge inclusion and seek alternative strategies to control scope creep.

Off-base resources are particularly problematic because they may be under the control of different entities.

For example, the following may be needed to support mission critical functions and should be considered:

- Water
- Waterfront/Shipyard
- Wastewater
- Communication
- Transportation and logistics
- Health and safety
- Security
- Food supply

During stakeholder meetings, identifying the characteristics of the microgrid elements is a strategy for controlling growth and is necessary for the ultimate performance specification of the microgrid. The following are characteristics of microgrid critical assets and systems:

- Time Basis
  - Loads should be identified as to how long after power outage they are needed (uninterruptible, seconds, minutes, hours, days, and weeks)
  - How long must load be supplied each day?
- Load Requirements
  - Full load, peak load, average load, or minimized load (can the load be subdivided into critical and non-critical, can control systems be used to drop non-critical load)?
- Alternatives
  - Is the function mobile, can it move to another site?
  - Can the function be performed by another command?

During the iterative stakeholder process, the design team will negotiate the microgrid performance with stakeholders. Pertinent questions include how fast will it come up, how much power will be delivered and at what time of day, and how long must it function without outside resources. Priority of power will be identified along with utility load shedding and utility restoration plans.

Facilitators must manage the process. Expand thinking to ensure each aspect necessary for mission integrity is considered, and then aggressively narrow the scope by focusing only on the systems that are necessary to support the mission. Depending on the complexity of the demand, the Base Command may want to enlist third-party support from NAVFAC. The Navy "can" conduct Distributed Energy Resources Grid Optimization Services (DERGOS) analysis or assist with finding outside consultants such as Sandia National Laboratory or a qualified engineering consultant to help identify critical loads. See Section 4.1.1 for more about DERGOS.

Based on the outcomes of the stakeholder meetings, the critical loads and their characteristics will be identified but may need to be revisited as future engineering analysis identifies issues such as cost or technology. The design team should carefully document the process in case something needs to be revisited.

Mission and the time horizon will affect critical load issues related to fuel supply chain, water and food supply, staff accommodations, and logistics.

3.2.3 Load Analysis

If an AMI system is installed to collect data in support of the microgrid feasibility study, the cost should be included with project cost. The AMI system may later return value by being incorporated in the microgrid system to manage operating cost in normal mode and optimize the microgrid when in island mode.

Load information is used to determine microgrid resources needed and for designing the microgrid system. During the initial study, the feasibility load analysis can be challenging. An AMI system, which is increasingly used, can provide detailed data. However, for specific loads, AMI data may not be available. During the feasibility study, the engineering team will go through an estimating process using available information and, at the end of the process, assess the confidence of the estimate. If confidence is acceptable, the design team may proceed with feasibility knowing that better data may be garnered before preliminary design. Alternatively, the team may choose to pause, selectively install AMI equipment, and gather additional data before readdressing the load analysis problem.

3.2.3.1 System Load Estimates

Existing data are used to map the physical location of base loads and associated feeder systems. Along with the physical location, a high-level electrical one-line diagram is created to show characteristics of the system, including relative position of critical and non-critical loads, transformers, breakers, and load-limiting devices. In some cases, the design team may want to inventory major loads such as large motors that support critical loads.

Normally, any point of utility connection has a meter with an AMI system or some form of continuous output. If AMI data exist, the difference between total base load and AMI metered load can be used to estimate and create a load curve for the remaining loads. Additional techniques that may be used to determine this include the following:

- By studying the available load curves based on season, time of day, day of the week, holiday, workload, outside temperature, and operating information and discussing the requirements with building and system owners, it is often possible to refine estimates.
- For certain building types, such as office buildings, typical load information for the building design and use may be available.
- For some large, non-critical loads, it may be possible to make a rough estimate by dropping the load and seeing how much the closest upstream meter moves.
- For critical loads with existing emergency generators, the generator output during past utility outages is a good indicator of load that must be supported by the new microgrid.

Ultimately, designers will need at least a spreadsheet model of loads (critical and non-critical).

3.2.3.2 Peak Loads

The microgrid must support the peak-load demand of critical systems when they are engaged in normal mission activity. During normal operation, peak loads at a typical installation and for typical building occur mid-afternoon and are often the result of normal activity, which includes air conditioning loads. Air conditioning is not necessarily mission critical. The engineering analysis should include options for managing loads, including loads in critical buildings that are not mission critical. It might be a strategy, for example, to connect the microgrid control system existing site and building control systems system and modify the operation of building systems when in microgrid mode.

At the same time, mission-critical systems may be in standby mode during normal time and energy use will be ramped up during mission activity. The engineering team needs to understand these operations and provide appropriate capacity.

3.2.3.3 Thermal and Non-electrical Loads

During analysis, the design team should pay attention to thermal and other non-electrical requirements, such as heating, specialty functions, cooling, water, wastewater, and pollution-abatement systems. These systems normally require electricity and the opportunity to modify the non-electrical load may create an opportunity to modify the electrical load.

Thermal heating may be an opportunity to incorporate a combined heat and power system.

3.2.4 Generation

3.2.4.1 Engine Generators:

The foundation of any microgrid system is the generators that supply power during a grid outage. The design team will need to inventory the **existing generator capacities**, which could be conducted along with the load analysis. Existing emergency generators may be connected to form a microgrid or they may be used to supplement a microgrid if they are outfitted with appropriate switchgear, controllers, and communication systems.

Some notes regarding generators:

- Emergency generators are often oversized. Collecting historical information about load versus capacity during previous electrical outages will help identify unused capacity.
- Emergency generators are generally not designed for continuous service. If the microgrid is expected to operate continuously for several days, emergency generators may be at risk of failure. Some emergency generators may be de-rated for use in continuous service applications. Fuel reserves for extended outage are often insufficient.
- U.S. Environmental Protection Agency (EPA) emission standards may not apply during emergency condition. Emergency generators do not need to meet emission standards and are not normally approved for service during non-emergency events. Thus, they may not be used as part of strategies such as load management or VPP operation.
- The latest EPA emission standards for stationary generators is known as the “Tier 4” standard. If the generators are used for applications other than emergencies, then the generators must meet EPA emissions standards **and** local emissions requirements. All new generators are required to meet Tier 4 standards.

The difference between the design load requirement (that is, the **required capacity**) and the existing capacity is the gap that must be filled by new generating capacity or other strategies. As an inventory of existing generation is conducted, the following specific information should be collected:

- Energy rating, average output and peak
- Fuel type and estimated operating fuel consumption (variable based on load, vendor data)
- Service type, emergency only or continuous service
- Emissions data and permitted use (emergency only?)

- Rated life between rebuild, time remaining to rebuild

3.2.4.2 Other Generation

In a military application, the microgrid is used to enhance energy surety and to support the base mission. At the same time, installations are progressing toward achieving the Navy's objectives of reducing its carbon footprint and reducing energy costs by adding renewable energy resources. As previously stated, EO 13693 requires all federal facilities to increase their use of renewable energy by a growing percentage each year. The renewable energy part of the microgrid equation is increasingly important; the renewable energy may offset fuel usage and extend the life of fuel resources in an emergency. Microgrid equipment may be incorporated to help more effectively use renewable energy resources.

Renewable energy options include hydropower, wave energy, wind, bio-fuel or biomass, geothermal, and solar. Many alternatives such as hydropower are a location-specific solution with significant permitting challenge. Wave energy may be viable, but is currently not commercial and also carries permitting challenges. For military applications, the three most viable renewable resources are wind, bio-fuel, and solar.

3.2.5 Energy Storage

The generators that provide the foundation of the microgrid system must be supported by sufficient energy storage to meet the minimum grid power-outage operating scenario without refueling. Over the past 20 to 30 years, numerous technologies ranging from compressed air in underground caverns to pumped hydro have been investigated and demonstrated for bulk energy storage. Most have had only limited success. For purposes of a military microgrid, the energy storage systems of interest are hydrocarbon fuels and batteries.

3.2.5.1 Hydrocarbon Fuel Storage

During Superstorm Sandy (2012), most critical power systems in the eastern United States failed because fuel was exhausted. During and after the storm, transportation and fuel supply systems were non-functional and critical systems simply ran out of fuel because the same event that disabled the electrical grid also took out the transportation and refueling systems.

Primary fuels are gaseous (natural gas or propane) and/or liquid fuel (diesel or aviation fuel). Natural gas is a low-cost fuel that is attractive from an environmental perspective because it burns clean with relatively low carbon dioxide emissions. If it is used as a fuel, an engineering analysis needs to consider the natural gas supply system and its ability to withstand design basis threats. Natural gas is stored in two modes, compressed natural gas (CNG) and liquefied natural gas (LNG). Storage systems for natural gas are expensive. CNG storage is typically in the range of 3,000 to 4,000 pounds per square inch and requires high-pressure compressors to compress pipeline gas and high-pressure storage vessels. LNG storage requires cryogenic systems; it is typically only used for ship transport where the weight and bulk of a CNG system becomes an issue. Both storage systems may be seen as hazardous and could be potential threat targets. Natural gas-fired generators are substantially more expensive than liquid fuel; unless they are operated extensively throughout the year, the fuel savings do not make up for capital cost.

In general, diesel fuel and aviation fuel are both readily available on a military installation. Storage and handling are well understood. Storage systems are low cost relative to gas systems.

3.2.5.2 Battery Energy Storage

Battery technology is evolving rapidly. Underlying technology is advancing and costs are decreasing. Because of the rapidly changing cost and technology environment, current data are required during the design process.

Advanced electronics provide battery storage systems with switching capability to enable sub-one-cycle response time. This allows battery storage to provide functionally near-uninterruptable power for motors and power systems. It may not be acceptable for demanding uninterruptable power supply (UPS) applications, such as computer systems.

On the down side, lithium ion batteries have had incidences of spontaneous fire and explosion. The primary cause has been localized overheating caused by control system failure or manufacturing defects, such as a particle in the anode or cathode material. Building codes are designed for older battery technology; NAVFAC recommends that lithium ion batteries be located outside of buildings or in dedicated application structures. Because most failures are the result of poor design or poor manufacturing practice, purchasing batteries from high-quality manufacturers is critical.

Quantifying the optimal capacity of battery energy storage is somewhat complex because the applications and theories for use are changing. Because of the high cost, current thinking is that batteries not be used as bulk energy-storage devices, but as rapid-response devices used to manage variability and add value within wind and solar applications.

Batteries may be integrated with conventional generators to supply power while generators are brought up to speed. This may be an alternative to the cost of operating conventional generators as “spinning reserve.”

Battery technology continues to develop rapidly. Lithium ion technology is changing and non-lithium ion technology is emerging. The design team should investigate options during design and up to the point of purchase.

3.2.6 Controls and Automated Switches

Along with generators, renewable energy, and energy storage, the control system and automated switches are the final elements of the renewable microgrid hardware.

- Synchronization control systems are used to measure electrical magnitude and phase angle of electricity as well as to synchronize time and coordinate the distributed power sources prior to merging.
- Control of the microgrid system including cyber-attack-resistant schema.
- Industrial controls for management of loads internal to buildings.
- Automated switches are used to disconnect non-critical loads and buildings so that the microgrid does not need to support non-essential load.
- Control software and its integration with existing site control system should be considered.

3.3 Microgrid Operating Procedures

The schema for operating the microgrid must be well defined. The defined operating procedure will become the basis for developing the control system and will be used to write code during detailed design and construction. The following sections provide a general description of typical operating procedures. During design development, the design team will add further detail, specifying the exact behavior of individual equipment and control elements.

3.3.1 Disconnecting from the Grid

There are two primary situations for totally disconnecting from the grid: emergency disconnect (unplanned disconnect as the result of grid failure) and planned disconnect (done in anticipation of an impending failure or for business reasons, such as operation as part of a VPP in support of the local utility).

Starting a microgrid system after unplanned grid failure with no generation resources on line is known as a “Black Start.” Black Start resources must have batteries or other means to start themselves. Because there is no utility reference, the resources must be able to define their own reference frequency and synchronize all resources uniformly to the reference.

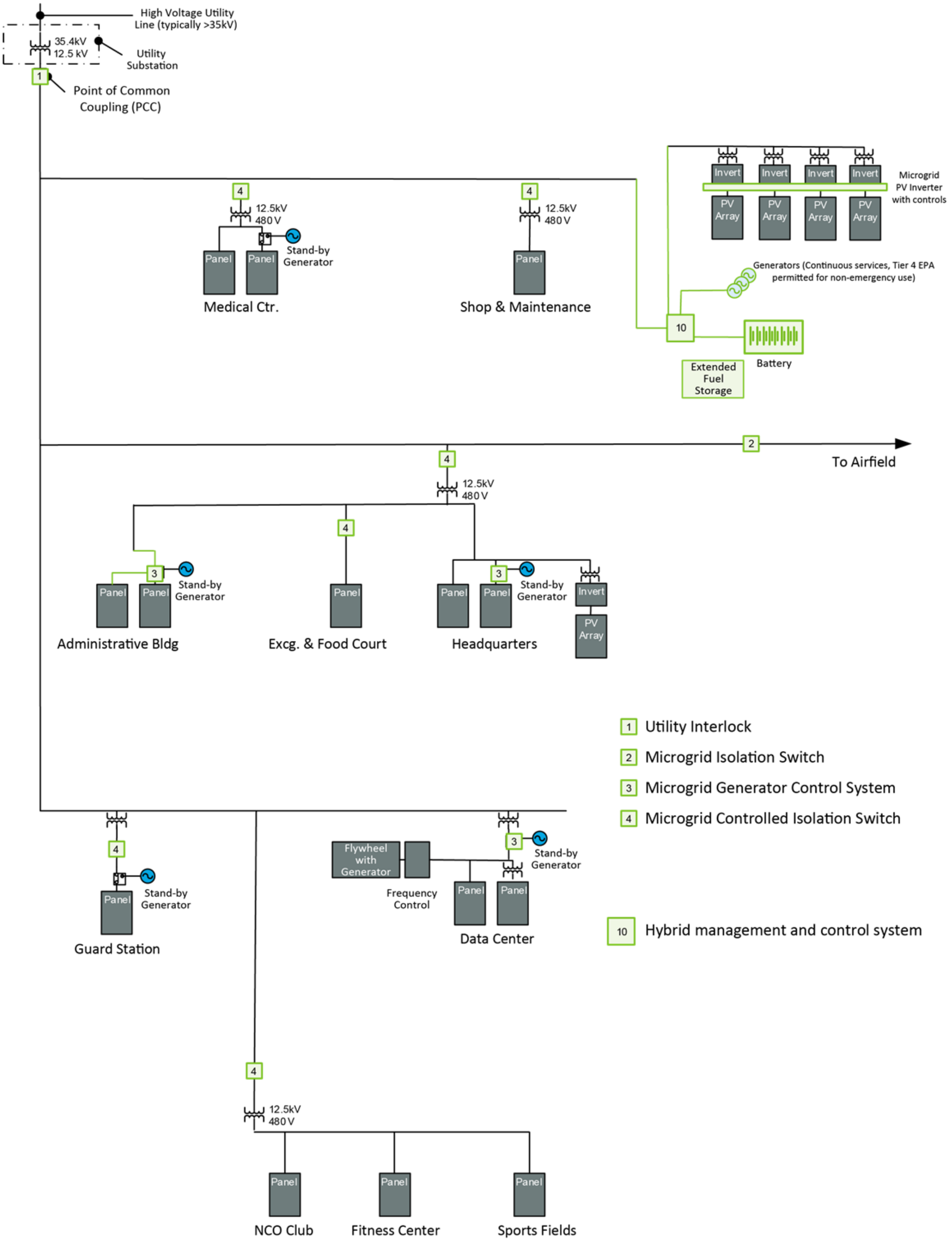


Figure 3-5. Hybrid PV Unit System

As previously mentioned, the microgrid strategy may be to build upon the existing system or significantly modify the system such that the microgrid is the first response. Numbers in parentheses are shown on Figure 3-5. The typical disconnect procedures are described below.

3.3.1.1 Grid Failure and Emergency Disconnect

If the microgrid builds upon existing systems:

- On loss of grid power, each building or load operates in a response to the power outage as it did before the microgrid was installed. For example, upon power loss, UPS power supplies engage and their generators start normally (the Data Center on Figure 3-5), other standby generators may start immediately or after a pause, depending on existence of a preset delay.
- At the option of the microgrid operator, if an extended outage is anticipated, the microgrid may be started. The programmed delay provides a cushion in the event that power to the grid is quickly restored and may be less disruptive to non-critical operations.
- The microgrid starts to build (Figure 3-5).

  The microgrid disconnects from the utility (the PCC is opened) (Figure 3-5 Item 1, Utility Interlocks) and the microgrid isolates from the airfield by opening the microgrid isolation switch (Figure 3-5 Item 2). By opening these two connections, the system boundaries are established.

  - Any UPS systems and emergency generators already operating remain operating. The microgrid takes operational control of any generators that are to become part of the microgrid (Figure 3-5 Item 3) and manages their use.
  - Buildings and loads that are not supported by the microgrid are disconnected by automated switches (Figure 3-5 Item 4, Isolation Switches). This process is known as load shed.
  - Any microgrid-essential generators that are not already operating are started and synchronized (the hybrid system generators, Figure 3-5 Item 10).
  - Emergency generators and UPS systems have been appropriately designed to integrate with the microgrid synchronize and connect.
  - Renewable energy sources are brought up, synchronized, and connected to the microgrid.
  - Microgrid-supported loads are connected to the microgrid one by one, starting with largest. Their emergency generators may remain on line to support the microgrid build depending on the microgrid design.
  - When all microgrid-supported loads are on line, the system operator brings the discretionary loads on line.
  - Microgrid energy resources are optimized.

If the microgrid is first response:

- The microgrid *immediately* disconnects from the utility (the PCC is opened).
- The microgrid essential systems start immediately (the hybrid system, Figure 3-5 Item 10) is started with batteries providing power until generators start).
- UPS systems start immediately.
- Normal standby generators do not start.
- Buildings and loads that are not supported by the microgrid are disconnected by automated switches (Figure 3-5 Item 4, Isolation Switches).
- Emergency generators and UPS systems have been appropriately designed to integrate with the microgrid synchronize and connect.
- Renewable energy sources are brought up, synchronized, and connected to the microgrid.

- When all microgrid-supported loads are on line, the system operator brings the discretionary loads on line.
- Microgrid energy resources are optimized.

3.3.1.2 Planned Disconnect from Grid

- Upon operator initiation, microgrid-essential generators and emergency generators that are part of the microgrid start-up and synchronize with grid frequencies.
- The microgrid starts to build.
  - Generators connect to the microgrid one at a time; as they do, the point-of-connection power meter begins to slow.
  - Renewable energy sources are already engaged, synchronized, and connected to the microgrid (no change is required).
  - Loads not supported by the microgrid drop off line one by one. The meter slows further and may reverse.
  - If the meter has not reversed, microgrid-discretionary loads drop off line in predetermined order until the meter reverses.
  - When the base’s net energy is negative, that is, the utility meter is reversed, the microgrid can safely disconnect from the grid.
  - Microgrid energy resources are optimized.

3.3.2 Reconnecting to the Utility Grid

Reconnecting the base from microgrid back to the grid is the same basic process for disconnect, but in reverse. The microgrid operator determines if the grid is stable and it is safe to reconnect. If safe to reconnect, the following reconnect sequence begins:

- Microgrid generators are synchronized with the grid frequency.
- The microgrid is reconnected to the grid. The net microgrid energy is zero or negative power flow.
- Loads not being supported by the microgrid are slowly added, one at a time. The objective is to maintain a steady escalation of power and avoid a disturbance that trips the breakers.
- Once all loads are on line, the microgrid generators begin powering down and drop off line one at a time.

3.3.3 Microgrid Security

Security must be considered for all aspects of the microgrid system, including fuel resources. Consequently, the design team needs to coordinate security issues both on and off base. In general, the physical security requirements for a microgrid are no different from the requirements for the general electrical system; the exception may be fuel storage. Large diesel and jet fuel storage tanks and, in particular, CNG or LNG may be targets of external threats.

Cyber-attacks of utility systems, especially on the grid, are increasing significantly. The design of the microgrid system must include strategies to assure that a cyber-attack on the grid does not also compromise the microgrid. Microgrid control design must follow the published UFC 4-010-06 for *Cybersecurity of Facility-Related Control Systems* (UFC 4-010-06 was in final review at the time this document was issued; contact NAVFAC for the latest information). The current approach relies on a more holistic strategy of ***building security in, not bolting it on***.

> Based on the organizational mission and details of the control system, the System Owner and Authorizing Official determine impact levels (LOW, MODERATE, or HIGH) for the control system. (UFC 4-010-06)

Risk management approaches developed by NIST are used to manage cybersecurity risk (NIST SP 800 82) A key objective of the cybersecurity design process is to minimize failure by reducing dependency on network systems and reducing extraneous functionality. Facility control systems are not information technology (IT) systems; they should not use standard IT system approaches and should not be connected to public systems, especially internet systems, and should not have remote access. The public internet system is one path for cyber-attack.

The microgrid control system design should include strategies to manage system failure in the event components or subsystems fail. The strategy should be to fail gracefully into modes of safe and secure operation. As part of the design process, a Risk Management Framework will be used. The RMF is the DoD process for applying cybersecurity to information systems, including control systems, by categorizing the system by impact as HIGH, MODERATE or LOW. NAVFAC Chief is the authorizing official (AO) that decides on the "Authority To Operate (ATO)" based on risk.

> As Defined by the National Institute of Standard and Technology (NIST), the Risk Management Framework (RMF) is "The process of managing risks to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation, resulting from the operation of an information system, and includes: (i) the conduct of a risk assessment; (ii) the implementation of a risk mitigation strategy; and (iii) employment techniques and procedures for the continuous monitoring of the security state of the information system." The Risk Management Framework details how Risk Management is applied to Department of Defense (DoD) information systems.

The subjects of control systems and cybersecurity can be complex. Additional design guide information is provided in the appendixes:

- The Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capabilities Technology Demonstration (JCTD) demonstrated a strategy for cyber protection of microgrids. A case study for the SPIDERS JCTD is presented in Appendix B. The cybersecurity section of the case study contains cybersecurity information specific to the JCTD. It is an example, rather than a template.
- Appendix C provides cybersecurity and platform architectural knowledge, including NAVFAC Smart Grid, Facility Engineering Operations Center and Navy Utilities Monitoring and Control Systems (NUMCS). NUMCS was created as a means to achieve RMF cyber requirements and should be considered in microgrid design.

3.3.4 Commercial Utility

Early in the microgrid design process, the design team should coordinate with the local commercial power utility. Discussions and contract negotiations may extend for more than a year. The following issues and significant opportunities could arise, depending on discussions with the commercial utility provider(s).

3.3.4.1 Technical

Technical issues exist related to disconnection from and reconnection to the power grid. If the microgrid is used only as a backup to the grid, disconnection is not an issue; the grid is down at that point.

Reconnection requires some care; connecting a large load that is not in phase with the grid could cause instability and take down the grid. While the microgrid is in island mode, it will use its own control system, including (if so designed) a global positioning system-satellite clock and synchronized phasors (synchrophasors) to produce real-time measurements of the microgrid electrical characteristics and coordinate the operation of the various distributed energy resources included in the microgrid. Before reconnecting to the grid, the microgrid needs to receive information from the grid and slowly adjust the microgrid to match the grid frequency. Only after the systems are synchronized can the microgrid reconnect to the grid.

Depending on the commercial utility and the design of the microgrid, the commercial utility may have restrictions on the amount of renewable wind or solar energy allowed, as these systems tend to introduce disturbances. The microgrid, correctly designed, will mitigate disturbances for its own operation, and should not present problems to the commercial utility. The topic needs to be discussed with the utility provider.

3.3.4.2 Commercial Utility Relations

Establishing a microgrid can significantly change the business relationship between the military installation and commercial utility. If the base uses a standard large service rate-structure contract, the microgrid can be used to manage energy and reduce the base's cost under its existing agreement. Additionally, the opportunity exists to coordinate the microgrid with commercial utility's operation; in such cases, the commercial utility may offer a modified rate schedule in exchange for a benefit. The commercial utility may be able to invest in the project capital or operating cost budget.

The Federal Energy Regulatory Commission establishes reserve requirements for utilities. Many utilities will offer alternative rate structures with incentives to customers if the customers can help reduce the need for utility investment in reserve resources (which are expensive and produce little or no revenue).

Curtailable Service. In exchange for rate benefits the customer agrees to reduce power usage according to a mutually agreed upon schedule.

Distributed System Generation (DSG). In exchange for benefits, customer agrees to bring generators on line at the request of the utility. There are limits on the amount of power that must be provided by the customer and the customer has the right to refuse under certain circumstances.

3.4 Safety Considerations in Microgrid Design

Microgrids use common equipment and technology generally used on military bases; thus, they present no significant new safety risks with respect to equipment and operation. There are four exceptions:

Energy Storage. Requirements for energy storage increase with a microgrid). The safety issues associated with liquid-fuel storage are well understood by the military community. Some microgrids may involve battery energy storage, but the building codes and manufacturing standards have not fully caught up with lithium ion battery technology. Installation of large-capacity lithium ion batteries in buildings is not recommended, so considerations will have to be made for external placement.

Electrical Safety. Personnel, especially electrical technicians, need to be aware that the grid is being energized by distributed resources. Care must be taken when working on the system to ensure there are no possible paths for energizing.

Integration. Care should be given to integrating the microgrid design with existing systems. This includes maintaining the continuity of site safety designs and protocols. Technicians should have one set of safety rules for the site.

System Grounding. Grounding needs specific attention when the microgrid is designed. The design team needs to assess grounding during all conditions of the microgrid, including all operational modes and all temporary modes that may conceivably exist during microgrid buildup and disconnect. Distributed generation and transformer systems may be disconnected and live at some point; thus, they need individual grounding systems. Careful analysis, including modeling, is required for both the grid connected and islanded modes (and all configurations between) to protect equipment and personnel during fault conditions.

3.5 Staffing and Training Requirements for Microgrid Operation

The intent is to use commercial off-the-shelf technology for the microgrid design; there should be no particularly unique staffing and maintenance requirements because a microgrid exists. PV solar collectors require periodic cleaning, but the maintenance is needed regardless of microgrid operation. Generally, any staffing increases for operation or maintenance should be in proportion to the quantity of equipment added for energy surety.

Maintenance and operational staff will require knowledge of digital control systems and training on the specific systems used for the microgrid. Understanding of staff capability is required at the beginning of design and may influence strategy and or cost.

If the microgrid is actively operated as a strategy for cost reduction or as part of a utility cooperation agreement, equipment use will increase and some elements (such as rotating equipment) may need additional maintenance.

Microgrids have a relatively sophisticated control system. Instrumentation and control technicians familiar with supervisory control and data acquisition (SCADA) systems and industrial control systems (ICSs) should be able to maintain the system with appropriate system training. If a site does not have a SCADA system or ICS, additional staff may be required.

In some cases, a site may not have staff familiar with advanced industrial control, direct digital control, or SCADA systems. In such instances, the microgrid may need a sustainment contract with a hardware or software provider (or independent contractor) to maintain the microgrid hardware and software systems.

3.5.1 Acceptance and Commissioning

The project construction plan will include a stage for equipment and software acceptance testing and system commissioning. Site staff should receive training before these stages and should be involved in these processes as part of their training.

3.5.2 Periodic Operational Testing

The microgrid system should be tested periodically to verify it will perform correctly when needed. This testing should be monthly or quarterly to verify working order of the equipment and system. Emergency generators also require periodic testing. Integrating the microgrid testing with the monthly or quarterly periodic emergency generator testing may be an option.

SECTION 4

4 Design Process

DON uses multiple processes when pursuing microgrid execution and various forms of contracting including Design Build (DB), Design Bid Build (DBB), ESPC, UESC, PPA and EULs. The following information targets DB and DBB approaches and should be modified as necessary for other contracting approaches.

4.1 Pre-Design

Once it is determined that a microgrid project is desired, proper planning that consists of identifying the requirements and developing the project documentation is needed. The requirements may come from a variety of sources and project documentation may involve multiple levels of approval. This planning phase is referred to as the pre-design (<5% of the project engineering effort) phase as defined in FC 1-300-09N (*Navy and Marine Corps Design Procedures*, 1 May 2014, [Change 2, 21 Aug 2015]).

Pre-design of the microgrid begins with a review of site evaluation/feasibility outcomes, specifically:

- Boundaries
- Building classification
- Critical infrastructure
- DBTs
- Performance goals
- Performance risk vectors
- Options identification and option evaluation
- Performance and cost
- Design solution options

The following sections present a general overview of the microgrid aspects of infrastructure design requirements. These sections are intended to identify and discuss project elements unique to microgrids with the understanding that, depending on the particular instance and strategy, there may be significant variation.

4.1.1 Distributed Energy Resources Grid Optimization Services

A DERGOS analysis is a NAVFAC Engineering and Expeditionary Warfare Center (EXWC)-facilitated process intended to identify potential risk/failure points associated with the inside-the-fence electrical system design and settings. The analysis highlights any significant technical issues and significantly improves the integrity of the design. In the pre-design phase of a microgrid project, the DERGOS team can be contacted to facilitate this process.

DERGOS deals with dynamic issues of the microgrid, such as transformer inrush current. Dynamic response issues are not necessarily evident from static calculations and they may not be issues when the system is connected to the grid. However, in microgrid mode, the microgrid's smaller size may result in more vulnerability to transient conditions, such as inrush currents, and result in dynamic instability.

DERGOS

(Distributed Energy Resource Grid Optimization Services)

Navy resource: The Navy has DERGOS available through NAVFAC EXWC in Port Hueneme, California. The DERGOS team can provide the following services:

- *AS-IS utility grid modeling and assessment, with dynamic and static power studies*
- *Scenario assessment – determine impact of proposed projects on the base electrical system*
- *Assess cybersecurity of the industrial control system using DHS' CSET tool*
- *Assess possible use of renewable resources and microgrids at the site to maximize penetration of renewable energy*
- *Develop designs to use existing ICS and generation systems in a broader base microgrid*
- *Optimize proposed and initial microgrid solution(s) to maximize energy security*
- *Provide a 35% design of a microgrid for your site*
- *Evaluate the condition of power quality of your electrical system, and provide design solutions to the problems found (working with EXWC Critical Power program)*

4.1.2 Computer Model Analysis

The DERGOS team will develop computer models for the design solution scenario(s). These models will assess dynamic response of the microgrid during all conditions:

- Grid failure
- Building the microgrid
- Operating the microgrid
- Reconnecting to the grid
- Planned disconnect and island mode
- Other options such as curtailing service or DSG

Building the model requires electrical one-line drawings of the intended design, assessing the condition of the equipment that will remain as part of the future design, transformer impedance (from vendor data), conductor sizes, and estimated cable lengths.

If the microgrid is to be constructed in phases (such as adding renewables, then generators, then batteries), it may be appropriate to model each phase.

DERGOS modeling may include the following:

- **Short Circuit Analysis**: Calculates the maximum available fault current at each bus in the system
- **Arc-Flash Analysis**: Determines the duration, amount of energy released, and minimum distance required to protect an individual from an arc-flash
- **Load Flow Analysis**: Provides magnitude and phase angle of the voltage at each bus and the real and reactive power in each feeder; analysis includes generators, transformers, and renewable resources
- **Voltage Profile Analysis**: Load-flow analysis is used to develop voltage profiles for each scenario; this is particularly important when renewable resources are included in the system as rapid output swings may introduce instability in the system; instabilities that may not be a problem for a large utility grid may be an issue for a microgrid

- **Coordination Study**: Determines the proper time versus current settings for medium-voltage relays based on feeder cables, transformer inrush current, generator size, and time-current setting of other equipment; objectives include devising relay settings to be tolerant to normal events such as inrush currents and still provide maximum protection from failure (fault) events, and having downstream circuit breakers clear first, thus compartmentalizing the outage to the smallest subsystem

DERGOS analysis may be performed at the beginning of design development to help eliminate scenario options or near the end of design development to identify issues in the final design.

4.2 Concept Design

At concept design, any pre-design options should be reduced to a single solution. The documents prepared will include 10-15% engineering drawings, basis of design (BOD), equipment selection, microgrid specific specification selection, network controls and communications, protection systems, security, commercial utility interaction, and system policy/operations. This design phase is consistent with FC 1-300-09N (*Navy and Marine Corps Design Procedures*, 1 May 2014, [Change 2, 21 Aug 2015]); however, due to the complex nature of a microgrid, additional details may be required in the concept deliverable.

4.2.1 Basis of Design

The BOD is intended to describe the design as an integrated system. It should be completed at the concept design phase, to provide documentation of the design intent and history of decisions. In a microgrid project, at a minimum, the BOD should contain:

- DERGOS analysis
- Narrative describing project goals and purpose
- Single one-line diagrams
- Instrumentation and controls system
- Detailed cost estimate and cost control plan
- Conceptual master schedule
- Environmental and energy plan (with required permits defined)
- Financial cost/benefit analysis and ROI analysis
- List of input/output devices required
- Strategy for network and maintenance of cybersecurity
- Functional description of operating systems
- Process and instrument diagrams (as appropriate)

4.2.2 Concept of Operations

A detailed description of how the system is intended to operate, the Concept of Operations (CONOPS) must address specific cases:

- **Grid Failure:** Specific situations under which the microgrid disconnects from the grid and the sequence of actions taken by actors to form the microgrid

- **Controlled Island Formation:** Specific sequence of actions taken by actors to form a microgrid while connected with the microgrid; conditions under which the microgrid is disconnected and any actions taken by actors after disconnecting from the utility grid

- **Reconnecting to the Commercial Grid:** Specific situations under which the microgrid reconnects to the grid and the sequence of actions taken by actors to prepare for reconnecting, connecting, and deconstructing the microgrid

- **Normal Operating Mode:** When connected to the grid, if the microgrid actors are used to optimize renewable energy use, unilaterally reduce utility cost or in conjunction with the commercial utility implement strategies such as curtailable service or DSG

4.2.3 Basis of Estimate

At the conceptual design phase, a cost estimate may be completed with a mix of vendor information and standard cost-estimating data. For specific high-cost elements such as generators, battery systems, transformers and renewable energy systems, the design team should request preliminary vendor budget pricing information on the specific high-cost equipment being planned. The vendor is typically supplied with system performance specifications (as opposed to a detailed design specification), and will typically provide the cost of an integrated system that includes an allowance for installation, specification descriptions, and estimated delivery schedule. The budget information is non-binding and the budget should include an allowance for potential changes or unknowns. The design team will be responsible for also identifying items such as management overhead, permits, and contingency. For standard systems that are not significant budget items, historical data may be used. In this case, estimating references such as RSMeans may be used.

NOTE: BOD cost data are often not site specific. However, estimating software such as SUCCESS has the ability to apply a location cost factor, which is a percentage ratio of the cost of construction in a specific location compared to the national average cost of construction. In addition, an installation may have an additional cost factor needed to compensate for issues such as site access, work restrictions, or work environments. These factors may drive the cost on a military site higher than the cost would be on a general site. Site-specific costs to consider include, but are not limited, to unexploded ordnance requirements, historical site preservation, and threatened and endangered species restrictions. Local personnel or NAVFAC can provide assistance with adjustment factors.

4.2.4 Master Schedule, Procurement, and Construction Plan

Microgrid projects may have some particularly troublesome schedule issues. Components such as generators, transformers, and batteries may have exceptionally long lead times (sometimes in excess of a year for large transformers). Procurement must engage early and delivery schedules of primary equipment may determine construction strategy and schedule. Because of the long schedules and the possibility of slippage, it may be necessary to mobilize and demobilize contractors and subcontractors throughout the duration of the construction. In addition to affecting the schedule, mobilization and demobilization may also have significant cost impacts.

Additionally, the sequence of construction needs to be considered. For example, if a high-penetration level of PV renewable energy is intended, the PV system may cause too much instability unless the battery system is installed first.

The microgrid will normally be integrated into an operating base. Schedule coordination with ongoing operations is critical, particularly for cut-in/tie-in work and equipment upgrade and swap out. These activities need to be scheduled around normal maintenance shutdowns, or closely coordinated with the affected component Commands for acceptable outage times.

Attention needs to be given to the funding strategies. This design guide emphasizes the fact that microgrids are fundamentally an approach to energy surety and are not built for the purpose of cost savings. It has also been a point that the lowest-cost energy-surety solution may not be the best value because the technology upgrades related to microgrids, integration of renewable energy, and power demand management may increase performance and produce attractive marginal savings relative to the incremental cost. Additionally, EO 13693 requires federal facilities to implement an increasing amount of renewable energy sources, which will result in significant renewable energy investment that could be enhanced by appropriate microgrid design and operation. As a result, funding for an integrated renewable microgrid project may be very attractive, but could involve multiple funding sources, such as the Military Construction Funding Authorization Document process and third-party financing organizations (who are repaid using the cost savings that is linked to their funding). In such cases, early planning for procurement of equipment and work scope packages is critical.

4.3 Delivery Method

4.3.1 Design Bid Build

For a DBB project, the information contained in the concept design will continue to be developed through the typical DBB process using the following design phases:

- Design Development (35% to 50% of the project engineering effort)
- Pre Final Design (100% of the project engineering effort)
- Approved Final Design

The requirements and deliverables for the DBB process are defined in FC 1-300-09N (*Navy and Marine Corps Design Procedures*, 1 May 2014, [Change 2, 21 Aug 2015]).

4.3.2 Design Build Request for Proposal

For a Design Build project, the concept documents should be incorporated into the NAVFAC DB six-part format to procure the system for the Navy, as defined in Chapter 11 of the FC 1-300-09N, *Navy and Marine Corps Design Procedures* (2015). The Design Build Request for Proposal (DB RFP) format and content should be developed as described in the Whole Building Design Guide, NAVFAC Design-Build master, as appropriate, available at the following location: http://www.wbdg.org/ndbm

SECTION 5

5 References

Environment America. 2015. “U.S. Counties Federally Declared Disaster Areas due to Extreme Weather, 2006 – 2011.” http://www.environmentamerica.org/page/ame/map-recent-weather-related-disasters. Accessed February 2016.

Lindsey, Bernie. 2012. “Navy Micro-grid and Smart-grid Efforts.” Prepared by NAVFAC Southwest Team Energy. 14 November. http://samesandiego.org/wp-content/uploads/2012/12/Navy-Micro-grid-Smart-grid-Bernie-Lindsey.pdf

National Renewable Energy Laboratory (NREL). 2011. “United States Annual Average Wind Speed at 80 Meters.” 1 April. http://www.nrel.gov/gis/images/80m_wind/USwind300dpe4-11.jpg. Accessed August 2015.

National Renewable Energy Laboratory (NREL). 2012. “Photovoltaic Solar Resource of the United States.” Developed by Billy J. Roberts. 19 September.

National Renewable Energy Laboratory (NREL). 2015. *Technical Report: 2013 Cost of Wind Energy Review*. NREL/TP-5000-63267. February. http://www.nrel.gov/docs/fy15osti/63267.pdf

Navigant Research. 2016. *Microgrid Deployment Tracker 4Q15*. Fourth Quarter 2015. https://www.navigantresearch.com/research/market-data-microgrids.

Sandia National Laboratories (SNL). *Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design.*

Sandia National Laboratories (SNL). 2013. “Microgrid Cyber Security Reference Architecture”. SAND2013-5472. Cynthia K. Veitch, Jordan M. Henry, Bryan T. Richardson, Derek H. Hart, Authors. July. http://prod.sandia.gov/techlib/access-control.cgi/2013/135472.pdf

U.S. Department of Defense (DoD). 2015. *Facilities Criteria: Navy and Marine Corps Design Procedures*. FC 1-300-09N. 1 May 2014, Change 2, 21 Aug 2015.

U.S. Department of Energy. 2008. *The Smart Grid: An Introduction*. Prepared by Litos Strategic Communication under contract No. DE-AC26-04NT41817, Subtask 560.01.04. http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages%281%29.pdf

U.S. Department of Energy (DOE). 2013. “White House Council of Economic Advisers and Energy Department Release New Report on Resiliency of Electric Grid During Natural Disasters.” August. http://energy.gov/articles/white-house-council-economic-advisers-and-energy-department-release-new-report-resiliency. Accessed January 2016.

U.S. Government Accountability Office (GAO). 2013. *Cybersecurity: National Strategy, Roles, and Responsibilities Need to Be Better Defined and More Effectively Implemented*. Report 13-187. February 14. http://www.gao.gov/assets/660/652170.pdf

Appendix A
Special Topics

Appendix A: Special Topics

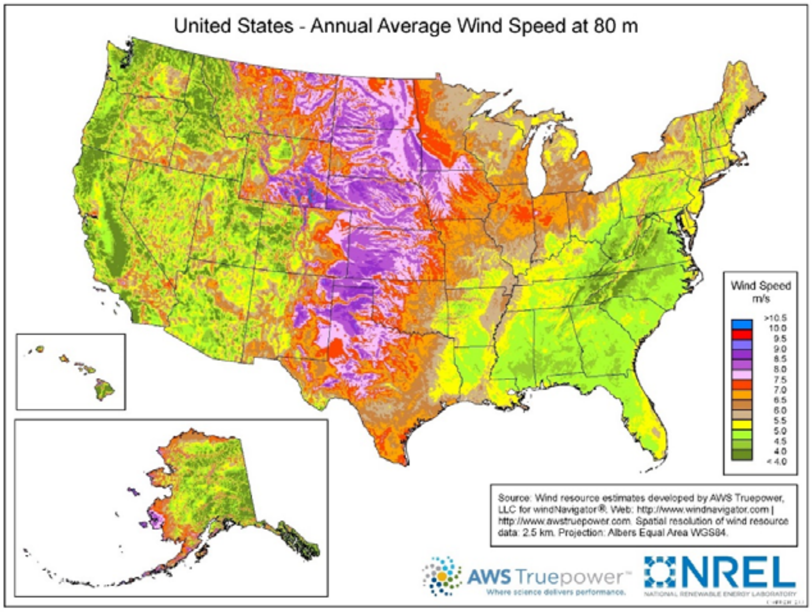
Chapter 1: Renewable Energy

Wind

Commercial wind turbines are cost-effective renewable energy resources and, depending on the location (Figure A-1), they may be integrated into a microgrid on a case-by-case basis. Where applicable, the levelized cost of energy (LCOE) may be less than $0.07 per kilowatt-hour (kWh) (National Renewable Energy Laboratory [NREL], 2015). However, LCOE is dependent on location and size of turbines. Location determines the wind resource capability and significantly affects site construction cost, including access and distance to the grid connection. A wind turbine’s maximum capacity (in megawatts [MW]) is determined by its physical size, including hub height, blade length, and generator size. The turbine’s capital cost per capacity ($/MW) is non-linear. The capital cost for a smaller turbine can be much higher per MW; thus, the smaller turbine’s LCOE is much higher.

Depending on the location, wind turbines may interfere with radar and may present issues for low-flying aircraft. Wind turbines, which have blades that rotate 130 meters or more above the turbine base, are generally installed on the hilltops or ridgelines to maximize exposure to the resource. As part of an onsite microgrid, wind turbines may be a significant challenge unless the site is sufficiently large to allow locating the turbines far from base operations.

In most cases, the variability of wind limits penetration to approximately 10 to 15 percent of the site load, because the resource is highly variable with rapid power swings that cause instability. The primary issue as a microgrid resource is the potentially long periods of no output. Although wind turbines are attractive for their ability to reduce carbon dioxide and energy costs, their application in a military microgrid design is generally limited to installations where the wind turbines can be located away from primary operations to prevent any interference.



Source: NREL, 2011

Figure A-1. Annual Average Wind Speed at 80 Meters

Bio-fuel

Bio-fuel is available from the commercial market and can be generated onsite. Commercial bio-fuel is commonly available as bio-diesel. Depending on incentives, bio-diesel may be attractive on a cost basis; however, for the purposes of this guide, using commercial bio-diesel is essentially an alternative to conventional diesel and does not have significant impact on the microgrid design.

Onsite-generated bio-fuel energy systems are very situation dependent. Typically, they are not large. Of the common options available, a likely alternative for a military base is methane recovery from a wastewater waste treatment plant. This technology is growing in use and should be considered.

Energy output from bio-fuel resources should be relatively stable and, conceptually, penetration could be very high. However, the availability of an onsite energy resource will limit bio-fuel's applicability.

Solar

Solar system costs have decreased substantially over the past few years to the point where, in many cities, solar energy is competitive with commercial grid energy on a cost-per-kWh basis. Costs are expected to continue to decrease substantially and cell efficiency is expected to increase over the next several years. Solar technology has sorted out several less viable options; the most common technology currently available is silicon-based photovoltaic (PV) technology.

Solar energy is somewhat more predictable than wind and is available during daytime when base operating loads are at peak levels. Even on overcast days, some solar energy is available. The most challenging situation for PV applications are cloudy days when output may change substantially as clouds pass over the collecting array. With batteries or generators (spinning reserve) integrated into the system to reduce spikes and add stability, solar PV can provide a high percentage of an installation's total energy.

Solar system design and capital cost is specified based on 1,000 Watts per square meter incident perpendicular to the panel. Consequently, the described system can be independent of location; however, the output is very location specific. The design team needs to be aware of the renewable energy conventions and adjust accordingly. Engineers should be cautious, because output is often specified in MW-direct current (DC). Actual usable alternating current (AC) output is approximately 20 percent less because of losses. Inverters are improving significantly and new inverter standards are anticipated from the Institute of Electrical and Electronics Engineers. The new standards will include advanced performance capability including voltage and frequency ride through and auto-reclose (or restart).

When requesting proposals, specifiers should ask for location-specific performance and AC output. Table A-1 provides a sample cost allowance breakout for a 1-MW fixed-tilt PV array.

Table A-1. 1-MW Fixed-Tilt PV Cost Allowances
(Provided by CH2M for illustrative purposes only; 2015 data)

Line Item	Example Cost
Inverters/Transformers	$230,000
Racks/Trackers	$354,000
BOP Mechanical Equipment	$31,500
BOP Electrical Equipment	$93,000
Material	$47,500
Combiner Boxes	$20,000
Startup Craft Labor, Materials, Supplies and Subcontract	$2,500
Labor	$141,000
Specialty Subcontracts	$600,000
Construction Indirect Costs (Support Services, Temporary Facilities)	$194,000
Engineering and Procurement	$108,000
Site Management, Labor, and Expenses	$91,000

Table A-1. 1-MW Fixed-Tilt PV Cost Allowances
(Provided by CH2M for illustrative purposes only; 2015 data)

Line Item		Example Cost
Project Management Labor & Expenses		$74,500
Insurance, Warranty, Survey, Training and Manuals, Taxes		$133,000
Subtotal		$2,120,000
Contingency (@ 5%)		$106,000
Escalation		$ -
Gross Margin (contractor profit @ 10% cost)		$318,000
Sales Tax Add/(Deduct)	TBD	$ -
Subtotal, Installer Contract		$2,544,000
PV Modules (Owner Supplied)		$1,088,500
Permits and Fees	TBD	$ -
Offsite Cost	TBD	$ -
Owner Cost	TBD	$ -
Total		$3,632,500

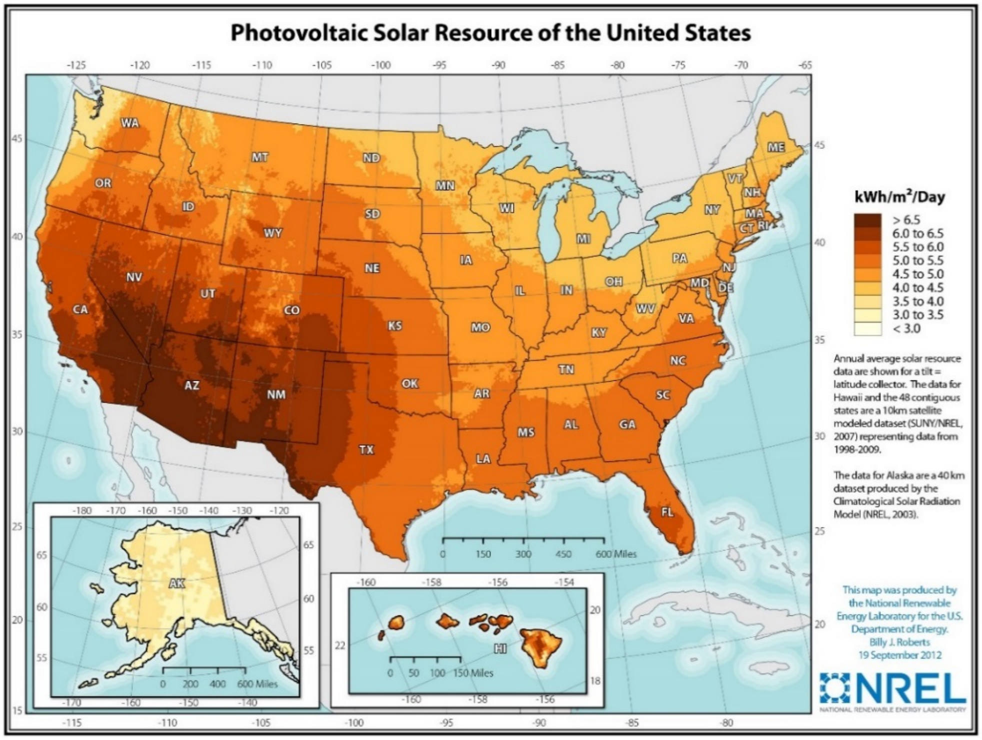
BOP = Balance of Plant
TBD = to be determined

The above example cost allowance is for a 1-MW-AC fixed-tilt PV array power plant with a total installed capacity of approximately 1,250,000 Watts, measured in DC, at standard test conditions. The facilities generally consist of the following:

- 4,537 PV modules: 300 Watts (owner furnished)
- 168 racks
- 12 21-string combiner boxes
- 2 500-kilowatt (kW) inverters
- 1 480-Volt (V)-12.47-kilovolt (kV) transformers
- Electrical/instrumentation and controls
- Associated BOP equipment
- Associated electrical equipment and bulks
- Outdoor switchgear
- Lighting
- Grounding
- Supervisory control and data acquisition system
- Security system
- 12.47kV overhead line to battery limit
- Civil/structural
- Civil and structural works
- 680 supports
- Galvanized steel columns (W6X8.5), 3.5-foot embedment depth
- Fencing
- Trenching
- O&M trailer (by owner)

Regarding the above allowances, engineers should have an understanding of how technological changes affect renewable energy costs. For the example in Table A-1, if the modules are available at a reduced cost, this impacts the line item “PV Modules.” Changes in the module performance (efficiency, or Watts per module) may result in fewer modules needed per kilowatt of output. This changes the required number of racks, BOP mechanical, BOP electrical, land cost, labor, contingency, and so on.

Once the system cost is established, the NREL LCOE calculator and the site solar data can be used to adjust for location and estimate the usable energy output for a particular installation. Figure A-2 provides solar resource data for the United States. A simple calculator for analyzing renewable energy projects can be found at the NREL site: http://www.nrel.gov/analysis/tech_lcoe.html.



Annual average solar resource data are shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states are a 10km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2009.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.
Billy J. Roberts
19 September 2012

Source: NREL, 2012

Figure A-2. Photovoltaic Solar Resource of the United States

Chapter 2: Generators

Generators are normally the primary power source for microgrids. Integrating generators into a microgrid and using generators strategically for various applications is discussed in the Renewable Energy Microgrid Design Guide. The following principles are critical to understand the role generators play in the microgrid:

- Existing generators cannot be operated during non-emergencies without being specifically permitted by the U.S. Environmental Protection Agency (EPA) and local authorities.
- The EPA's run-time limitations on emergency generators do not apply during emergencies.
- The latest EPA emission specifications for generators are Tier 3 and Tier 4. All new generators must be Tier 4.
- Existing generators can be converted to Tier 3 or Tier 4.
- Tier 4 operation may require low-sulfur fuel.

A critical decision about how to develop the microgrid concept revolves around the generator strategy—using numerous smaller generators at individual buildings or a few larger, aggregated generator locations that serve multiple buildings. The first strategy may be challenging if accessibility, space, fuel-storage capacity are limited.

The cost of smaller generators can be an issue. On a per-kilowatt basis, small systems may cost 50 to 100 percent more than larger generators. Figure A-3 illustrates generic industry data for the cost of a typical emergency generator. Although costs may be significantly higher at a particular military installation, the shape of the curve as shown on Figure A-3 illustrates how the cost of a diesel generator per unit of capacity drops rapidly with size until approximately 250 kW, at which point it stabilizes. Continuous service capability adds roughly 20 percent to the cost. Using natural gas as a fuel more than doubles the capital cost; consequently, natural gas generator applications are limited in microgrid use to situations of high annual hours where fuel costs dominate. Both continuous-service and natural gas generators are shown on Figure A-3 as single points at 500 kW as a relative reference; the generators are not available in all sizes. Manufacturers should be consulted for availability. The cost presented on Figure A-3 is generic industry data, not military-specific and should not to be used for estimating. The purpose of the figure is to show relative relationships. Although the shape of the curves, inflection points, and relative positions should be consistent between industrial and military installations, the absolute cost of systems installed may vary significantly.

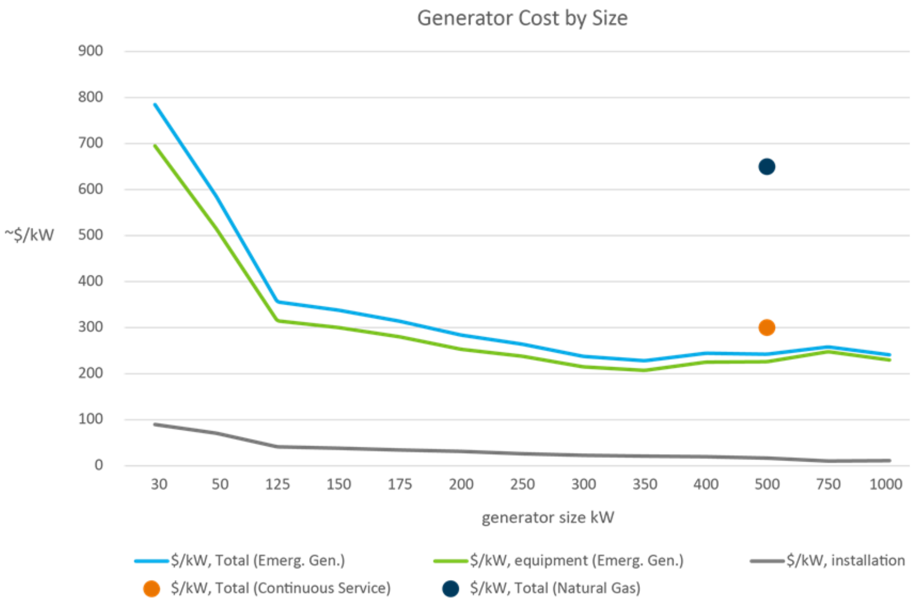


Figure A-3. Estimated Generator Set Cost ($/kW) by Size (kW)

Appendix B
SPIDERS Microgrid Conceptual Design

Appendix B: The SPIDERS Microgrid Conceptual Design

An objective of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capability Technology Demonstration (JCTD) project (2011-2015) was to inform the public regarding the cyber-secure microgrid technology while maintaining the confidentiality of information specific to each of the demonstration sites. To accomplish somewhat mutually exclusive objectives, the final report introduced a "Reference Design" military base as an example. It is a simplified composite of the three phases of the SPIDERS JCTD and exhibits significant technical characteristics of each phase. The SPIDERS Reference Design is provided as an illustrative example of a microgrid design process (appropriate to feasibility or conceptual stages of design).

Installation JCTD Reference Design

The SPIDERS JCTD Reference Design ("Installation JCTD") is a hypothetical moderate-sized facility in Hawaii. Installation JCTD houses command functions, administrative operations, a data center, maintenance facilities, and a small medical center. Along with some miscellaneous buildings and functions, Installation JCTD includes onsite barracks and residences to accommodate personnel. No mission-focused manufacturing, maintenance, port/marine, or other such large energy-consuming operations are conducted at Installation JCTD. Figure B-1 shows a satellite image and sketch of the buildings considered in the design.

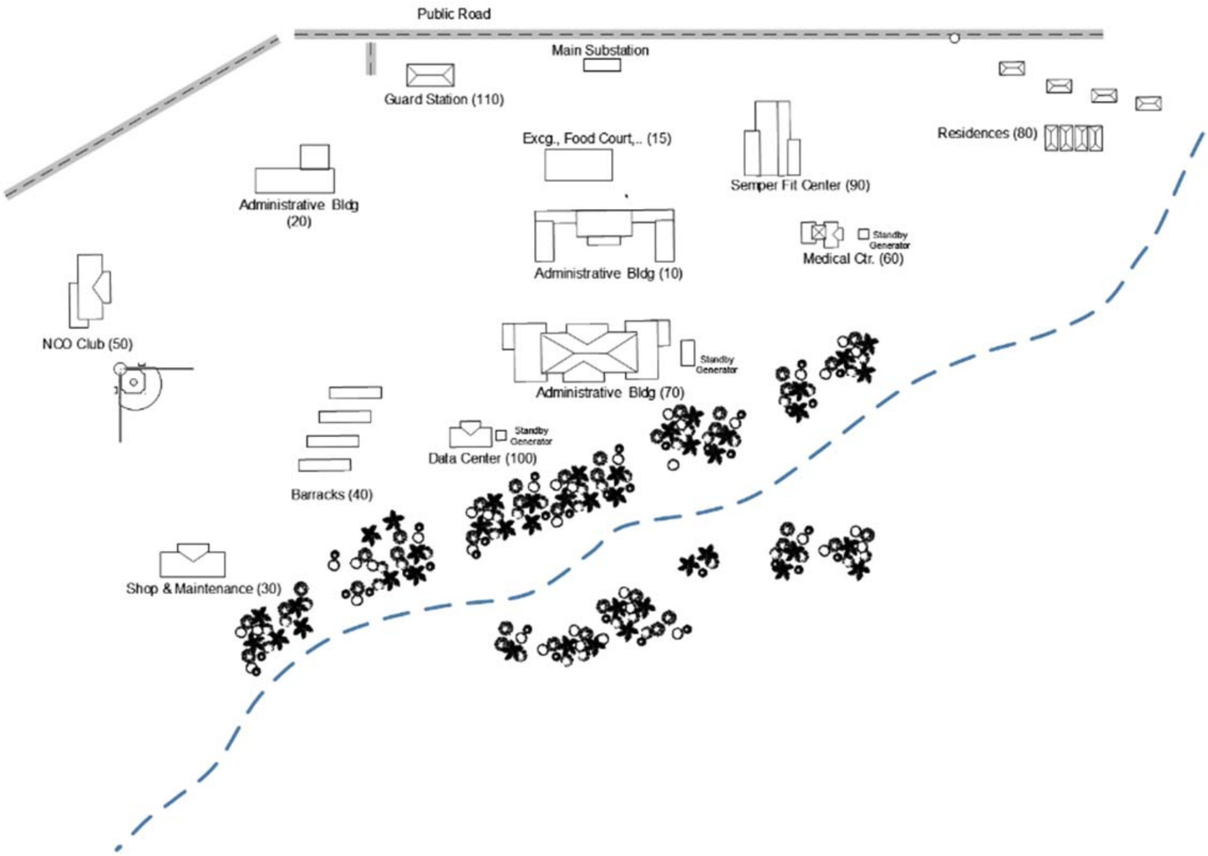


Figure B-1.Installation JCTD Reference Design

Background:

Most of the significant initial construction for Installation JCTD occurred in the 1940 and 1950s during and just after World War II. A second wave of construction occurred around 2000. Installation JCTD has essentially two high-voltage distributions systems. The west high-voltage distribution system was constructed during the initial construction phase. Both the newer east high-voltage distribution system and the original west system are 12,000V (Figure B-2).

The second wave of construction was highly focused on energy and most of the buildings constructed during this time are Leadership in Energy and Environmental Design certified. Typically, a microgrid design would begin with a base-wide energy assessment and energy conservation program. A recent energy audit had been performed under NAVFAC direction, and most of the easy-to-implement low-cost or no-cost energy conservation measures had been implemented. Consequently, the SPIDERS project was able to start immediately with microgrid design.

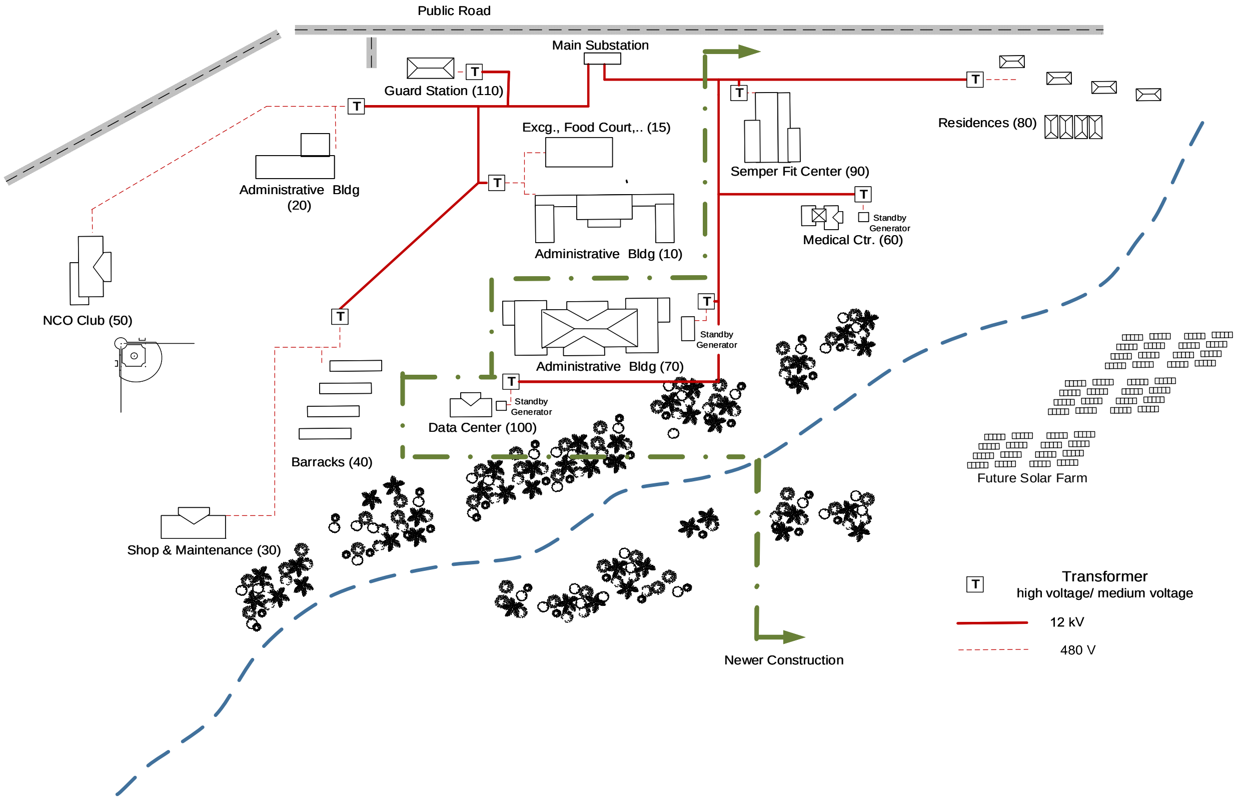


Figure B-2. Installation JCTD Pre SPIDERS Electrical Distribution System

Installation JCTD Data

Installation JCTD is approximately 200 acres in size. The local climate is very mild with little seasonal change. Except for hot water, heating requirements are minimal. Cooling loads exist year around, although in the winter much of the cooling can be accomplished by natural ventilation. Figure B-3 shows average temperatures.

Because Installation JCTD’s energy consumption is influenced by its air-conditioning loads and the microgrid includes a solar PV resource (with plans for a large solar farm in the future), solar radiation and cloud cover are important factors. Figure B-4 shows seasonal precipitation and correlation with temperature.

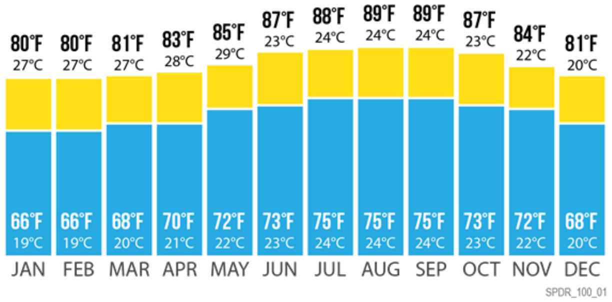


Figure B-3.Weather Data

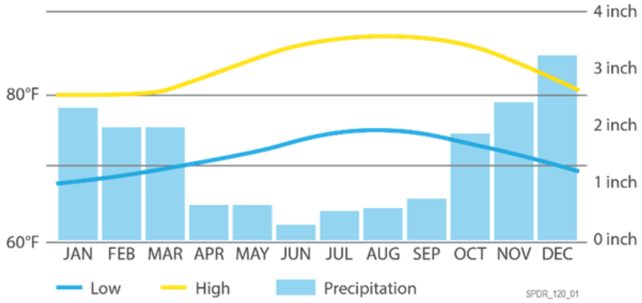


Figure B-4. Precipitation Data

http://www.usclimatedata.com/climate/honolulu/hawaii/united-states/ushi0026

Electrical Rate Schedule

Connection	\$400/month
Demand	\$21.00/kilowatt (kW)/month
Energy	\$0.15/kWh

Determination of Demand: The maximum demand for each month is the maximum average load in kW during any 15-minute period as indicated by a demand meter. The billing demand for each month is the highest of the maximum demand for such month, or the mean of maximum demand for the current month and the greatest maximum demand for the preceding 11 months, whichever is higher.

Existing Electrical Site Load

Like many installations, Installation JCTD does not have an electrical Advanced Metering Infrastructure (AMI). The primary meter is at the utility connection. Typical load profile over a year is shown on Figure B-5. Figure B-6 shows a typical peak season (August) single-day demand profile.

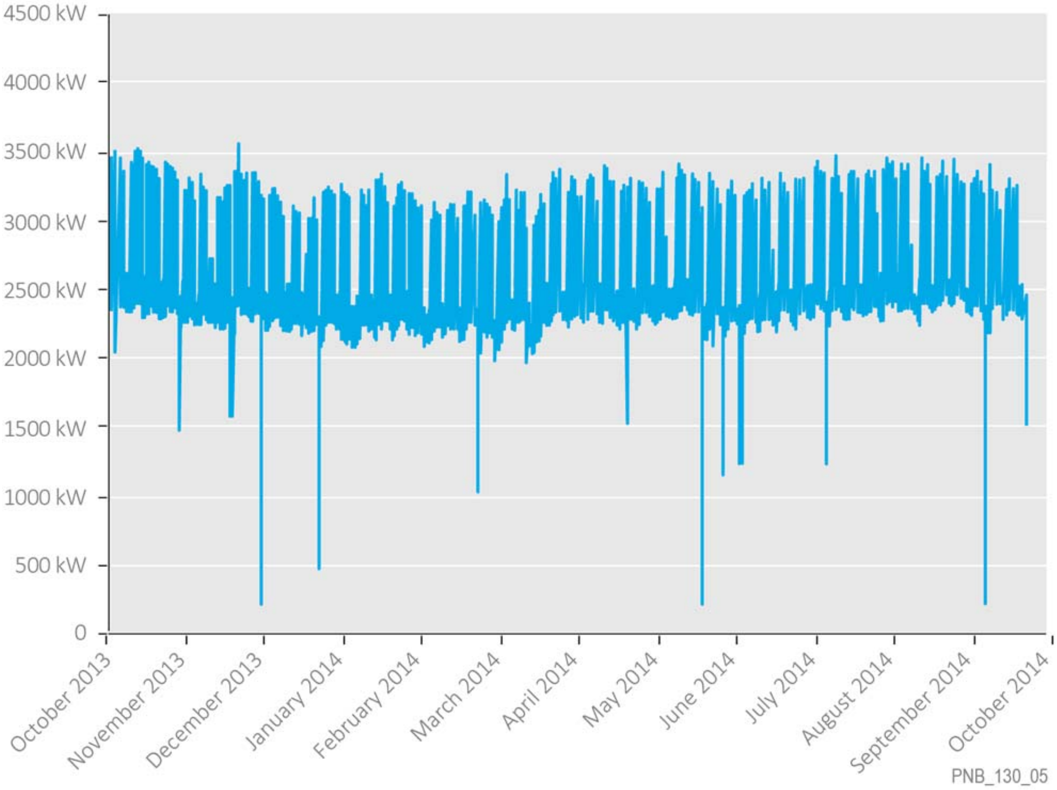


Figure B-5. Installation JCTD Meter Data

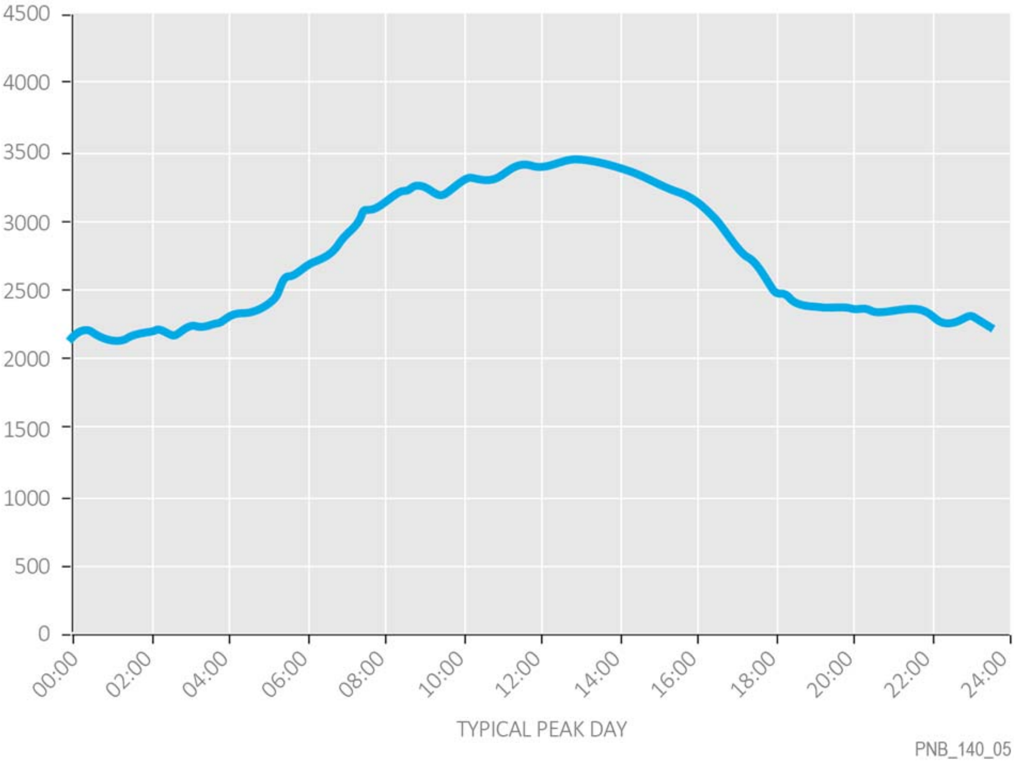


Figure B-6. Installation JCTD Typical Peak Season Single-day Demand Profile (kW)

Based on the annual weather data and annual utility data, August and September are generally the months when peak demand is set; they are also the months when precipitation is low. The Installation JCTD analysis team believes demand peak is set by cooling system loads on days of bright sun, consequently the team believes a future solar farm could be a significant tool for managing the site electrical demand charge. This will be discussed later in the report.

Site Electrical Building Loads

Although Installation JCTD does not have an AMI system, a Pacific Northwest National Laboratory (PNNL) team estimated the individual building loads during the energy audit it conducted approximately 3 years ago. The PNNL team used the Facility Energy Decision System (FEDS) tool combined with audit observations to categorize buildings; the building categories were used to estimate building electrical loads. Table B-1 shows the buildings on Installation JCTD and their estimated annual energy loads. For reference, the table also shows the average energy intensity per square foot for each building (calculated from the energy use estimate and building area) and estimated energy use as a percentage of total site for each building.

Table B-1. Installation JCTD PNNL FEDS Data

Building Name	Building No.	Area (ft^2)	Annual Electrical (kWh)	Average Energy Intensity (kWh/ ft^2/ yr.)	Percent of Total Site
Administration Building	10	240,000	3,960,000	16.5	17%
Exchange, Food Auditorium	15	75,500	1,887,500	25.0	8%
Administration Building	20	97,000	2,536,507	26.1	11%
Shop	30	24,000	180,000	7.5	1%

Table B-1. Installation JCTD PNNL FEDS Data

Building Name	Building No.	Area (ft^2)	Annual Electrical (kWh)	Average Energy Intensity (kWh/ ft^2/ yr.)	Percent of Total Site
Barracks (total of 4)	40 Series	48,000	384,000	8.0	2%
NCO Club	50	7,000	154,000	22.0	1%
Medical Center	60	80,000	2,000,000	25.0	8%
Administration Building	70	230,000	8,280,000	36.0	35%
Residences (total of 8)	80 Series	14,400	122,400	8.5	1%
Fitness Center	90	29,900	777,400	26.0	3%
Data Center	100	35,000	3,500,000	100.0	15%
Guard Station	110	3,900	93,600	24.00	0%
Total Site Annual			23,875,407	kWh/year	

ft^2 = square foot (feet)
kWh/ ft^2/yr. = kilowatt-hours per square foot per year

Microgrid Conceptual Design Development

Under direction of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) JCTD Integrated Design Team the initial conceptual design for Installation JCTD was developed by a concept Design Team consisting of representatives from Camp Smith, Pacific Command, Sandia National Laboratory (SNL), and other SPIDERS contributors. The conceptual design process generally followed the Energy Surety Design Steps outlined in the SNL course book *Fundamentals of Advanced Microgrid Evaluation, Analysis, and Conceptual Design*.

Boundaries

As a first step, in keeping with the SNL process, the boundaries of the system were established. For the SPIDERS program and in this reference design case, the boundaries are assumed to have previously been established. In actual situations, the establishment of microgrid boundaries and perhaps dividing the "system" into multiple microgrids can significantly influence the solution (both technical and cost). Although not part of SPIDERS JCTD scope, establishing proper boundaries is a critical part of a microgrid conceptual design process.

Building Classification

Next, the Design Team identified and classified critical loads, interdependency, and locations of electrical equipment. This was done via a structured process with stakeholders. Stakeholder meetings were facilitated by the conceptual Design Team.

As part of the process, the Installation JCTD buildings/assets were classified into one of the following categories:

- **Microgrid Essential** – These building or assets are required to support the microgrid as designed, and could include buildings with significant backup generators that support the microgrid, distribution-level PV arrays, or other supplemental resource. At Installation JCTD, one building was classified as microgrid essential, as shown on Figure B-7.

- **Microgrid Supported** – These buildings or assets are connected to the microgrid and their infrastructure is designed such that their loads are served by the microgrid under most conditions (utility managers can always decide to manually disconnect a building if deemed necessary, but the design assumes these building loads are always carried by the microgrid). These facilities may or may not have generators; if they do, the generators are not required to be operating to keep the microgrid stable (such as Building 60, Medical Center). A prime example of this would be facilities with only renewable generation assets (such as Building 90, Fitness Center).
- **Microgrid Discretionary** – These buildings have the ability to be connected to the microgrid, but the can also be isolated at the discretion of the installation commander. Ideally, these buildings have automated switches for connecting/disconnecting from the microgrid, but this could be a manual function and still serve the purpose.
- **Non-microgrid** – These buildings are outside the microgrid boundary.

The stakeholder final classification of buildings at Installation JCTD is shown in Figure B-7.

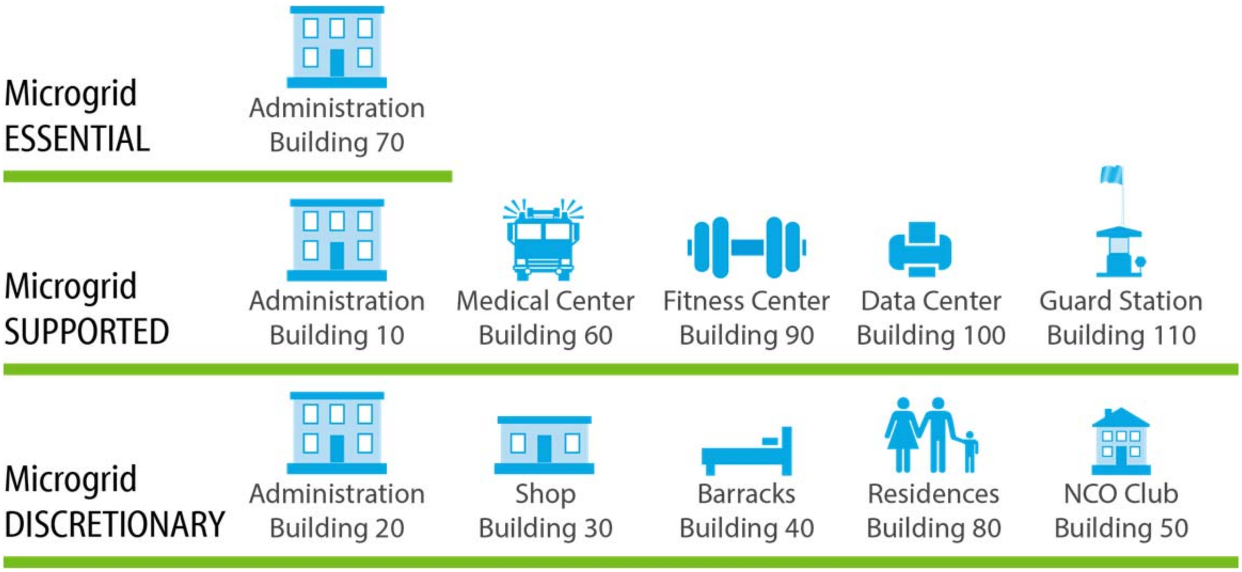


Figure B-7. Installation JCTD Building Classifications

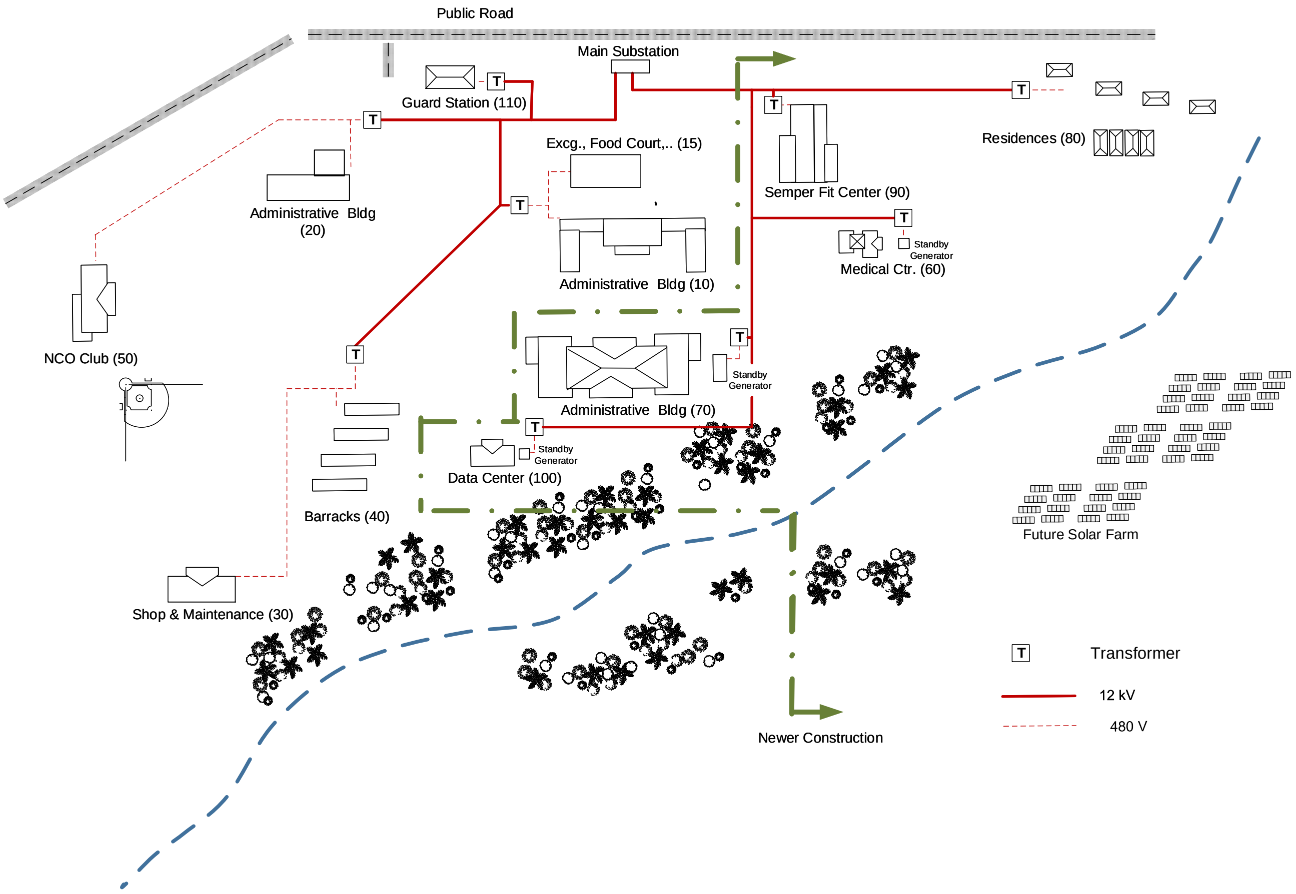
Defining Critical Infrastructure

Once buildings were classified, the concept development team worked with the Installation JCTD engineer to research the site's electrical distribution system. The relationship of all infrastructure to critical buildings and critical loads was used to identify critical infrastructure.

Note: For Installation JCTD, the SPIDERS JCTD scope defined critical infrastructure to be on the base and only electrical. However, one may imagine a situation where a critical building "X" depends on a non-electrical infrastructure service "Y", perhaps a natural gas pressure boosting station located offsite. Service "Y" then becomes critical even though it is not connected to a critical building.

Electrical routing paths and a map of building locations was developed for Installation JCTD. Figure B-8 is a high-level map of the building existing physical and load locations along with a general concept of the pre-SPIDERS high-voltage distribution system.

The team identified critical distribution systems, generators, switches, breakers, and similar, as noted on Figure B-8.



Note: The line separating newer (eastern) construction from the legacy (western) construction. This demarcation ultimately influenced the design concept.

Figure B-8. Pre-SPIDERS Electrical Distribution System

Design Basis Threats

Following stakeholder meetings and development of building classifications and load map, attention was turned toward establishing the design basis threat (DBT) and performance goals. This was done again with stakeholder teams facilitated by the conceptual Design Team. DBT development included interviews and discussion with the local utility and presentation of utility information to the Installation JCTD stakeholder team.

Based on discussions with city, county, local utility, Installation JCTD command, and Installation JCTD engineering, DBTs were identified. DBTs include hazards such as hurricane, flooding (resulting from excessive

Table B-2. Installation JCTD Design Basis Threat Analysis

Design Basis Threat	Probability	Impact
Flooding	🔴	🔴
Cyber Attack	🔴	🔴
Hurricane	🔴	🟡
Utility Outage	🔴	🟡
Earthquake	🟡	🟡
Volcanic Eruption	🟡	🔵

Legend:		
	High	🔴
	Medium	🟡
	Low	🔵

rain), local utility service risk, and cyber-attacks on the power grid. These DBTs were ranked, as shown in Table B-2.

In addition to cyber-attack, the following assumptions were associated with DBTs:

- Torrential rain associated with tropical storms (not necessarily hurricanes) are common. Because Installation JCTD sits on a hill, landslides caused by flooding could be a serious event.
- Hurricanes are common but utility systems in Hawaii are well hardened against the wind. Impact is expected to be medium.
- Utility outages are common in Hawaii, but are typically isolated and usually relatively short duration.
- Small earthquakes are common, but large events are few and systems are designed to be resistant.
- The probability of volcanic eruption is low on the older islands. On islands with active volcanic activity, eruptions cause localized events.

Performance Goals

Performance goals were developed with Installation JCTD executives, the Installation JCTD engineer, and local electrical utility. Final performance goals were ultimately determined based on the requirement to maintain the base’s mission integrity. In the case of Installation JCTD, the most important utility system performance goal defined was the ability to operate microgrid-essential and microgrid-supported buildings for up to 5 days with one emergency refueling and up to 3 days without any refueling capability. (Because of where Installation JCTD is located, it was anticipated that flooding could wash out roads, and up to 2 days after the flooding event would be needed for temporary repair or a workaround solution.)

Performance Risk Vectors

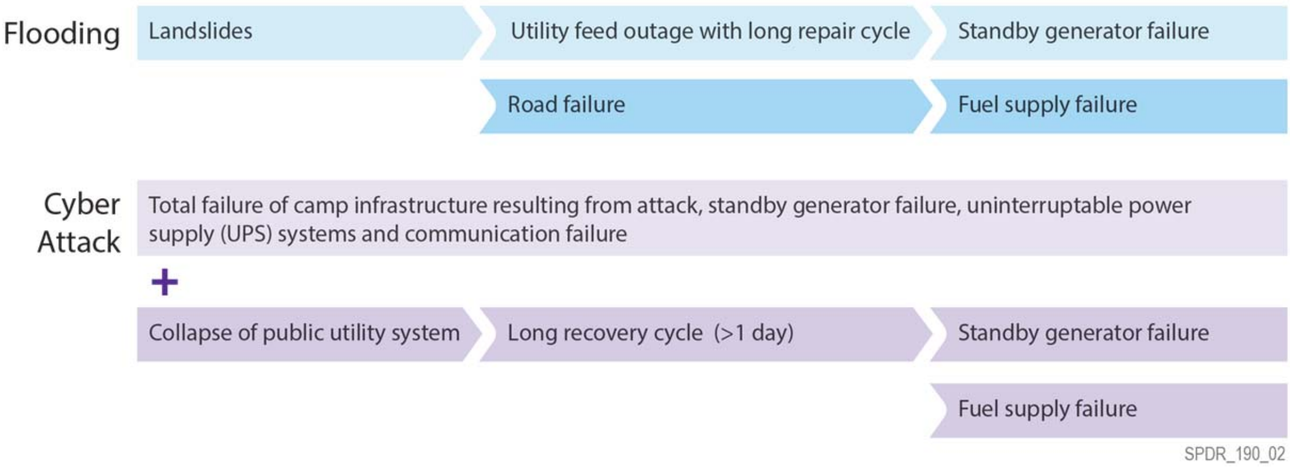


Figure B-9. Performance Risk Vectors

For each of the top DBTs (those having a high impact, as shown in Table B-2), the concept Design Team in conjunction with the base engineer and local utility engineer examined “Risk Vectors,” as shown on Figure B-9. It became apparent that the installation had insufficient generating capacity and insufficient fuel storage to withstand an extended outage. The highest-level risk vectors are described in the following sections.

Develop High-level Options for System Modification and Hardening

The Installation JCTD identified two overarching issues that threaten the performance goals: generator capability and fuel supply.

Generator Capability

Standby generators are generally designed for short operation periods; continuous operation is not intended and can result in generator failure. Although any specific generator may not fail if each building is served by a generator and generators are not interconnected to provide backup, it is probable that a single generator's failure may jeopardize the mission.

Some of the Installation JCTD buildings identified as critical did not have standby generators.

Fuel Supply

Existing generators have fuel capacity for only a few hours and the installation does not have a large-capacity fuel storage system. If roads become impassable during a DBT event, fuel delivery could be delayed and generators will begin shutting down within hours.

The team identified the following needs:

- Add generator capacity
- Interconnect generators to provide redundancy
- Add significant storage capacity

The following three high-level options were considered:

1. Add building-dedicated generators to unprotected buildings, add fuel storage systems at each generator, and construct an electrical interconnection system including an interconnected control system among the standby generators.
2. Same as Option 1, but replace the need for the interconnecting electrical system with a portable backup generator that could be moved around to serve as a backup to the individual standby generators.
3. Add a central generator set to support unprotected buildings and backup protected buildings. Include a central fuel storage system. Distribute power using the existing medium-voltage system.

Evaluate Options for Performance and Cost

The high-level options were evaluated relative to their performance; that is, their ability to successfully handle DBTs, as well as their performance and cost. As part of the performance and cost evaluation, potential operating cost savings and other "non-cost" benefits were evaluated and included opportunities for demand reduction and energy reduction as part of the evaluation. This iterative approach included circling back to options and developing hybrid options.

Design Solution

Ultimately the evaluation process lead down the following logic path:

1. Existing generators were standby generators and had run-time design limitations. In some cases, the generators were very old and unreliable. Continuous operation for 5 days or more could not be assured. Installation JCTD needed new, continuous-service generators capable of meeting all microgrid-supported design loads. There was also a financial incentive to use generation sources at Installation JCTD during grid-tied operation to provide ancillary services to the utility.
   a. EPA requires stationary generators to meet Tier-4i standards if used in non-backup power modes
   b. Existing standby generators could be used to supply N+1 redundancy to the central system when backup power is required, thus the central system did not need to incur N+1 redundancy cost.
2. Fuel was minimal. Consequently, a new onsite fuel-storage facility would be needed.

   a. Natural gas was not an option. The supply system did not currently exist and would be vulnerable to the same threat vectors as the electrical system.
   b. LNG storage was eliminated as an option:
      i. Handling infrastructure for LNG was not locally well developed.
      ii. Installation JCTD is next to a residential community, safety risks of LNG storage were a concern.
   c. Existing generators are diesel-fired. Introducing generators fired by a new fuel would require new storage systems.
   d. Diesel was selected as the best fuel source. In Hawaii, diesel is a primary fuel source, supplying over 70 percent of the islands' energy. The fuel is readily available in large quantities.
3. Installation JCTD has plans and space for a future solar PV farm. By planning the solar farm into the microgrid as a "Mission Essential" element, peak energy consumption could be reduced during full solar hours.
4. The most cost-effective strategy for engaging the essential, supported, and discretionary elements of the Installation JCTD microgrid is a system of automated "sectionalizing" switches at the voltage-system distribution level.
   a. The distribution voltage system includes the "old system" and "new system."
   b. A conceptual strategy was established whereby sectionalizing switches would automatically disconnect microgrid discretionary buildings if load shedding were required, either individually or in groups. If in groups, members of a group could be manually disconnected from the group and the remaining members could be reconnected by manually closing segments of the sectionalizing switch.

Installation JCTD Post Microgrid Design

As a general approach, because the SPIDERS JCTD is used to investigate the implementation of microgrids at existing facilities, an implicit requirement is that the system needs to be as unobtrusive as possible within the existing infrastructure. This is necessary to avoid cost and disruption. The requirement has been extended by the project team to include the ability to revert to non-SPIDERS operation by turning off SPIDERS mode on the graphical user interface (GUI) of the microgrid control system. Turning off SPIDERS mode on the GUI prevents the supervisory controllers from making decisions or implementing control actions. Thus, the installation of a SPIDERS system does not degrade the existing system in any way. With this "**Do No Harm**" philosophy, the SPIDERS system is designed to "lay over the top" of the existing system instead of being a wholesale replacement of it. In addition to facilitating the transition to a SPIDERS-type system, this also allows the continued use of a traditional transfer switch-based isolation system to be the default mode for compliance with life-safety codes should the SPIDERS control system fail for any reason.

Typical of sectionalizing switch

The SPIDERS microgrid solution is based on the following concepts:

- Use of medium-voltage switching for microgrid segmentation and building
- Use of low-voltage bypass breakers near existing generator automatic transfer switches (ATSs) to minimize disruption of the power to facilities during construction (compared to alternative approaches) and allow for maintaining the current backup power operation as the default response to power outages
- Integration of a neutral deriving transformer as a ground reference for the microgrid when islanded from the utility and to support single-phase loads within the medium-voltage distribution system while operating as a microgrid
- Continuous availability of adequate spinning reserve in the central prime power diesel generators to carry the design load should PV and/or stationary batteries trip off line

Medium-voltage Distribution and Generating System Modifications

Figure B-10 shows physical locations of new assets and revisions to the high-voltage distribution system for Installation JCTD.

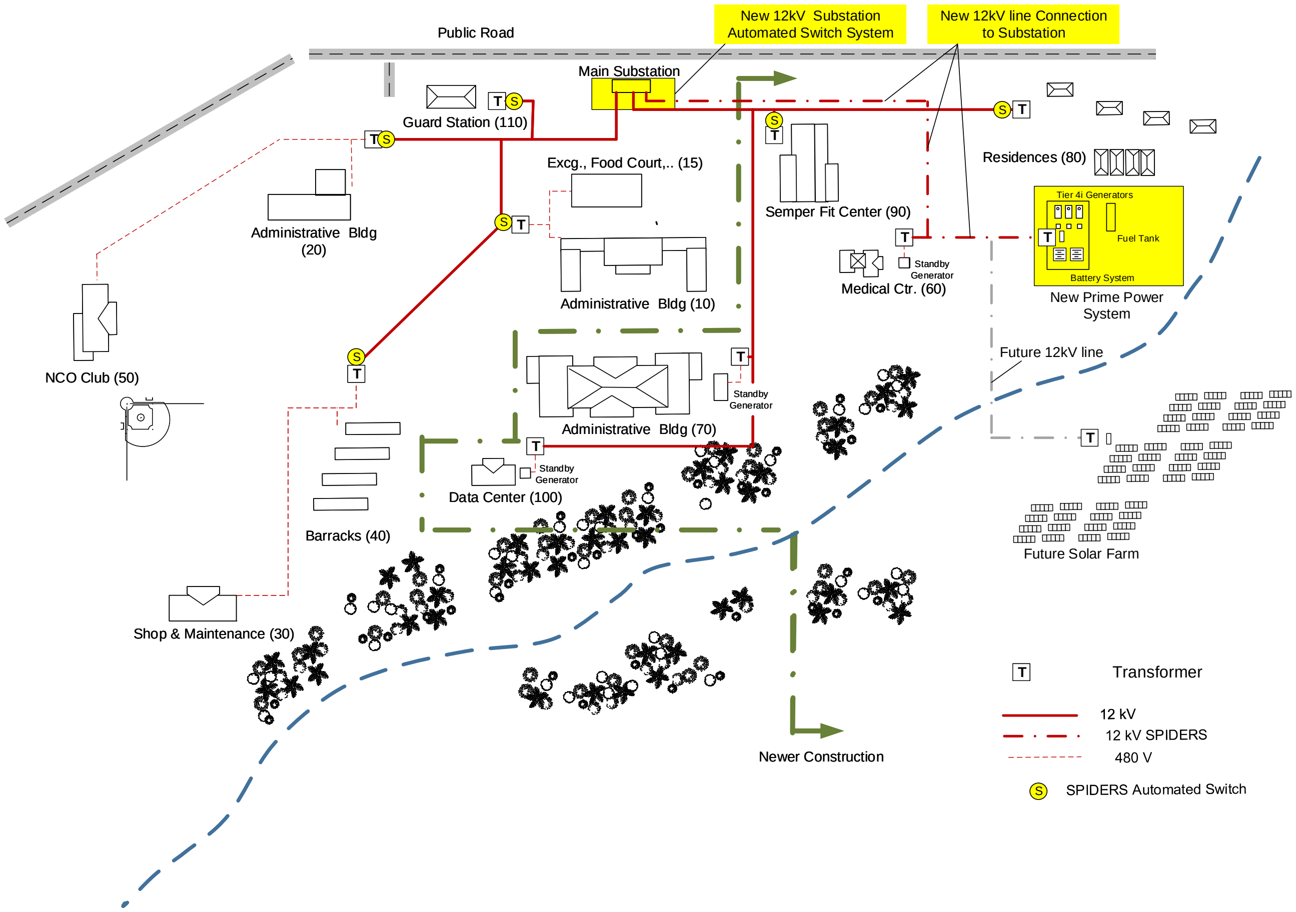


Figure B-10. Revised Distribution System at Installation JCTD

Segmenting switches, which are critical to the operation of the microgrid, are shown on Figure B-10. Note the following on Figure B-10:

1. A “prime power” generator pad has been added to the east of the medical center and a new underground medium-voltage feeder has been added to connect the new generator pad with the existing installation substation and medical center. The Medical Center is supported by the microgrid but not essential to operation.
    a. Installation JCTD had essentially two distribution systems, both starting at the substation. The lowest cost and least complex solution for adding new electrical generation was to connect new generation at the substation and use new substation breaker controls and sectionalizing switches to segment the existing distribution when in microgrid mode.
    b. If the generators had been connected to the eastern distribution system (which was physically closer), a failure of the eastern system could disable the western distribution system.
    c. The generator pad includes a microgrid battery system that is continuously connected to the Medical Center. Manufactured as an integrated system, it includes controllers and hardware for “seamless” transfer to generator power.
    d. Upon power failure, the batteries provide energy to the Medical Center while the generators ramp up, synchronize, and stabilize.
2. The Medical Center was disconnected from the eastern high-voltage distribution system and is now connected to the new prime power line. A technology demonstration goal of the SPIDERS JCTD was to show capability to protect critical loads with near UPS power quality. In the event of power loss, the system supports the Medical Center load in approximately 1/4 cycle and maintains its operation until the prime power is running. This system demonstration could apply to any load not needing true UPS-quality power (for example, not a computer). By connecting the Medical Center, the Design Team hoped to reduce potential damage to medical equipment such as a magnetic resonance imaging machine.
3. The future PV system will be connected at the new generator pad.
    a. The microgrid be used to stabilize the PV system’s variations.
    b. PV power can be integrated with the prime power system operation

Concept of Operations

The first principle of the SPIDERS microgrid Concept of Operation is to **“Do No Harm.”** Upon a power-failure event, each building or load responds as designed in the pre-SPIDERS mode. The exception is the Medical Center, which is a special part of the JCTD; its response is discussed below. Upon loss of utility power, Installation JCTD operations have the following responses:

- **First 1 second**
    - **Data Center Building 100.** The Data Center is equipped with a kinetic energy UPS. The UPS system is effectively in series with the grid power; upon loss of power, stored kinetic energy continues to drive the unit’s internal generator without interruption for a short duration. The Data Center is a Mission Essential facility that also has a backup generator. Upon loss of power, the building’s ATS initiates the generator and, once up to speed, the generator provides power to critical loads within the Data Center. The Data Center continues to operate on generator power until internal control logic “sees” an extended period of electrical supply stability at the Data Center feeder. The SPIDERS microgrid has no impact on the Data Center’s initial response.
    - **Fitness Center (Building 90) Solar System**. Electrical codes require solar power to immediately drop off the utility distribution system if voltage or frequency is outside certain boundaries. This

  is a safety requirement to avoided backfeeding the system and potentially injuring utility workers. When a loss of supply voltage is detected, existing relays in the solar power control systems drop the Fitness Center's panels off line. As is typical with these systems, the Fitness Center PV systems will begin coming back on line in a predetermined sequence approximately 3 to 5 minutes after the supply power has been restored and stabilized. The SPIDERS microgrid has no impact on the Fitness Center solar system.

  - **New Medium Connection**. The new line is disconnected from the utility substation and the Medical Center and prime power system become a sub microgrid within Installation JCTD.
  - **Medical Center (Building 60)**. The SPIDERS JCTD targeted the Medical Center as a demonstration example for newer technology. The Medical Center has an existing standby (emergency) generator. Typically, in the event of grid failure, the Medical Center generator would be up and running in less than 30 seconds. While the Medical Center experiences a very short period of "black," it also experiences potential power surges and sudden frequency shifts.
  - However, the SPIDERS microgrid demonstrates a new operation. The Medical Center is connected to a new resource, the microgrid prime power station, which consists of multiple generators and a large battery system with high-speed "seamless" capabilities. With the new system, upon loss of utility power, the Medical Center is connected to a sub-microgrid supplied by battery power from the generator pad system. The Medical Center has no noticeable loss of power. The battery is sufficient to power the Medical Center until the generators are up and running. Within the first minute, the generators are in phase and take over supplying power to the Medical Center. Although equipped with an emergency generator, the facility does not recognize a loss of power and, therefore, the facility's emergency generator will not be required to respond. If, however, the batteries and prime power generators fail, the Medical Center standby generator will come on line as usual.

- **Minute 0 to 1.** Except for actions in the first second described above, Installation JCTD sits "black," waiting for grid power to return.
- **Minute 1 to 10.** After a predetermined wait period existing standby generators connected to the Administrative Building (Building 70) are started. Once generators are up to speed, Building 70 disconnects from the medium-voltage system and connects to generators.

  The remainder of Installation JCTD stays "black" and in pre-SPIDERS mode would have remained "black" until utility power returned.
- **Minute 10 to 15.** The sub-microgrid formed with the Medical Center is extended. Formation of the microgrid can be manually started at any time by the installation engineering operations. In this automatic mode, the microgrid waits 10 minutes for return of utility power. The microgrid is formed as follows:
  - New breaker controls at the substation disconnect Installation JCTD from the local utility's power grid.
  - Simultaneously, new automation on distribution switches open and disconnect the installation's subsections from the distribution system.
  - After disconnecting the installation from the utility and disconnecting the high-voltage distribution system from loads (a process that takes less than 10 seconds), the new prime power supply line is reconnected at the substation (Note: it had been disconnected in the first <1 second). The east and west distributions are energized. The Medical Center (Building 60) is connected to the prime power station and Administration (Building 70) is added to the microgrid. The building 70 generators provide N+1 backup to the prime power generators, as a result building 70 is microgrid essential. The Data Center (Building 100) remains disconnected

using existing standby generation. The Design Team did not want to integrate the Data Center generators as an essential element of the microgrid.

- In an orderly fashion (at the option of the Installation JCTD engineer), the opened segmenting switches are closed and the following buildings brought back on line using prime power:
  - Guard Station (Building 110)
  - Administration (Building 10) and the Exchange (Building 15)
  - Administration (Building 20)
  - Fitness Center (Building 90) (solar power comes on line after 3 minutes)
- After each load is added, the system checks itself. If all is in order, standby generators at the Data Center and Administration (Building 70) are allowed to drop off during the efficiency optimization phase.
- Installation JCTD is in full microgrid mode. Discretionary loads are added manually at the option of the Installation JCTD engineer. For long outages, it is anticipated that certain loads within buildings may be shut down, thus freeing capacity for discretionary loads.

When the future solar farm is operational, it will be integrated into the system as the microgrid is formed.

When utility power is returned and stable, the operators will begin microgrid shutdown. The prime power system will synchronize to utility power, the substation will connect to the utility, and the prime power system will begin shutting down. Any solar power available will remain on line as usual.

Microgrid Cybersecurity Controls Overview

The fundamental SPIDERS JCTD concept stems from DOE's "Energy Surety Microgrid" approach to energy assurance. Distributed generation and storage are placed on the load side of the grid and on a local basis; storage and generation are matched to the critical loads. As with traditional backup power, when a utility grid outage occurs, the local single building systems "island" and detach from the base high-voltage distribution system. The difference in the microgrid mode is that the complete base detaches from the utility grid; after the base is detached, the individual single building systems reattach to the base distribution system.

Microgrid Control

As discussed, this project was designed to minimize cost and retain functional existing infrastructure. The cyber-secure microgrid control system was, therefore, designed to "lay over the top" of the existing electrical and control systems. Individual control systems for the microgrid components (for example, some generator controls, individual breaker trip units, and automatic low voltage transfer switches) were present prior to the start of the project start. However, in many cases they could not be controlled as a single coordinated system. Where necessary, components were upgraded with the addition of commercial off-the-shelf (COTS) controllers that also provided the ability to communicate and accept commands from a supervisory control system.

Example secure microgrid charging station
Image Courtesy of IPERC

The SPIDERS control system used COTS control elements. These component controllers were overlain with a master controller to provide microgrid supervision, management, and cybersecurity. The component-level controls continue to operate autonomously, but the overall coordination and sequencing commands originate with the master control system. This allows components to respond extremely quickly in response to instantaneous demands or electrical safety issues while still being managed as part of the coordinated microgrid. The SPIDERS control system is accessed through a human-machine interface and operated through a GUI. The GUI allows the system operator's access to monitor and control the system, and download historical information.

Unlike traditional centralized SCADA systems, the SPIDERS supervisory control is provided by a community of distributed intelligent power controllers with embedded software that can be installed on a wide range of power sources, distribution gear, and/or end loads that make up a microgrid.

Network elements are connected with a common communication system, creating a responsive, resilient "collective intelligence" that continuously optimizes performance. The system employs a set of general rules of operation that accommodate the overall desired behavior of the system during normal operation and when contingencies or equipment failures occur. The system can accommodate changing conditions of the equipment without the need to be reprogrammed. This also eases the adaptation to arbitrary additions and deletions of equipment and facilitates incorporating algorithms for increased sophistication and inevitable load growth.

Cybersecurity Enclaves

As previously noted, the SPIDERS cybersecurity approach makes use of concepts developed by collaboration among the DoD National Laboratories. This approach employs the practice of forming enclaves, as described in SNL's "Microgrid Cyber Security Reference Architecture" (SNL, 2013).

The technology was applied at Installation JCTD by dividing the microgrid system into groups of actors and segregating these groups into "enclaves." Figure B-11 shows the enclaving strategy for Installation JCTD.

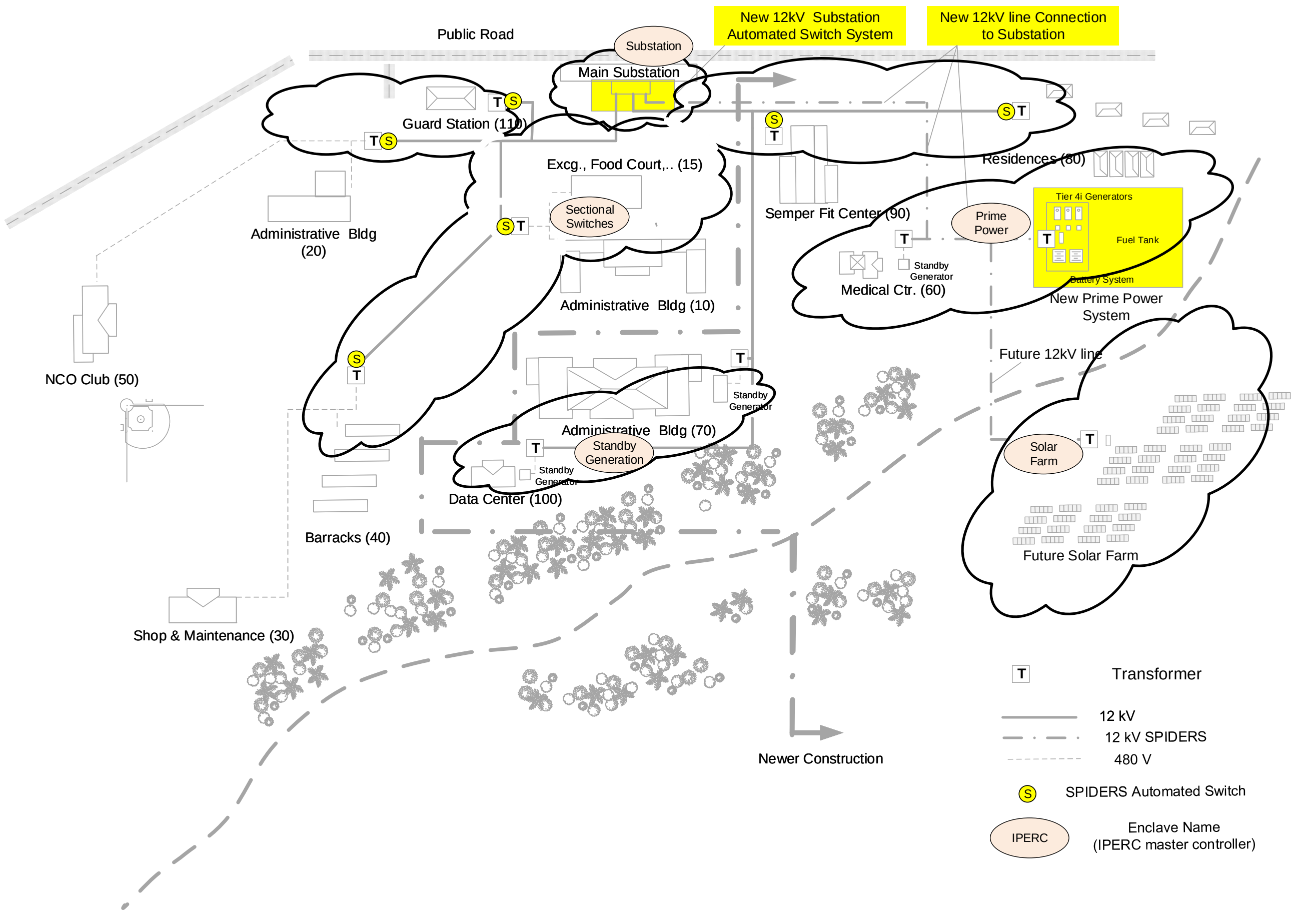


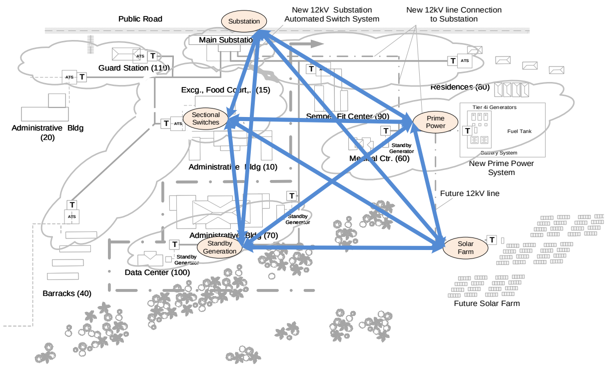
Figure B-11. Installation JCTD Enclaving Strategy

Enclaves are generally shielded from any outside communication; communication with other enclaves is only through a highly secure device. In the Installation JCTD case, the device was specifically designed for secure control of microgrids. Communication between enclaves and with the outside world (if allowed) is “denied by default.” That is, unless a specific communication is allowed (“whitelisted”), it is denied.

Within an enclave, communication is unrestricted among actors. Within the enclave, vendor-supplied control systems are allowed to operate equipment and standard ICSs manage and control processes and operations.

Generally, enclaves are created from actors that have a logical need to work together or are in physical proximity. Enclaves generally work autonomously; it is a design objective to minimize the need for communication between enclaves. Whitelisting communication becomes relatively easy because the need to communicate is limited.

Limiting communication outside of an enclave reduces the need for communication bandwidth. The SPIDERS team’s analysis found **that limiting communication bandwidth within the network is an effective strategy for reducing vulnerability to cyber-attack**.



Inter-Enclave Communication

JCTD controllers are each capable of full system control and all communicate with each other. This allows a failed unit to be replaced by any of its equals. The inter-enclave communication is highly flexible (although whitelisted and possibly bandwidth restricted).

Cybersecurity

As control systems naturally evolve to become more like enterprise information technology systems, the security of those controls must also evolve. The SCADA systems that have been used over the last several decades were not developed to handle the potential cyber-attack threats of the current era. Nonetheless, an enormous existing infrastructure is in place that needs to be protected; protective measures are being widely applied across industry and government. This is primarily being accomplished by overlaying security measures on top of existing systems. A good starting point for implementing security measures can be the use of the following security guidelines:

- **National Institute of Standards and Technology (NIST) 800-82**, Guide to Industrial Control System Security
- **NIST 800-53**, Attachment 1 Security Controls, Enhancements, and Supplemental Guidance
- **DoD Instruction (DoDI) 8500.2**, DoD Information Assurance (IA) Certification and Accreditation Process
- **Committee on National Security Systems Instruction 1253 App I**, ICS Security Overlay Vendor and DoD Security Guides for Network, OS, Application, and similar

Risk management assessments of the Installation JCTD system have been conducted including the following:

- Department of Homeland Security Cybersecurity Evaluation Tool
- JCTD Red Team Attacks and component penetration testing
- DoD Information Certification and Accreditation Process
- Independent static code analysis to discover and correct vulnerabilities within the software code

Schedule

Implementation of a cyber-secure microgrid may have substantial variation in schedule. A representative schedule is shown on Figure B-12.

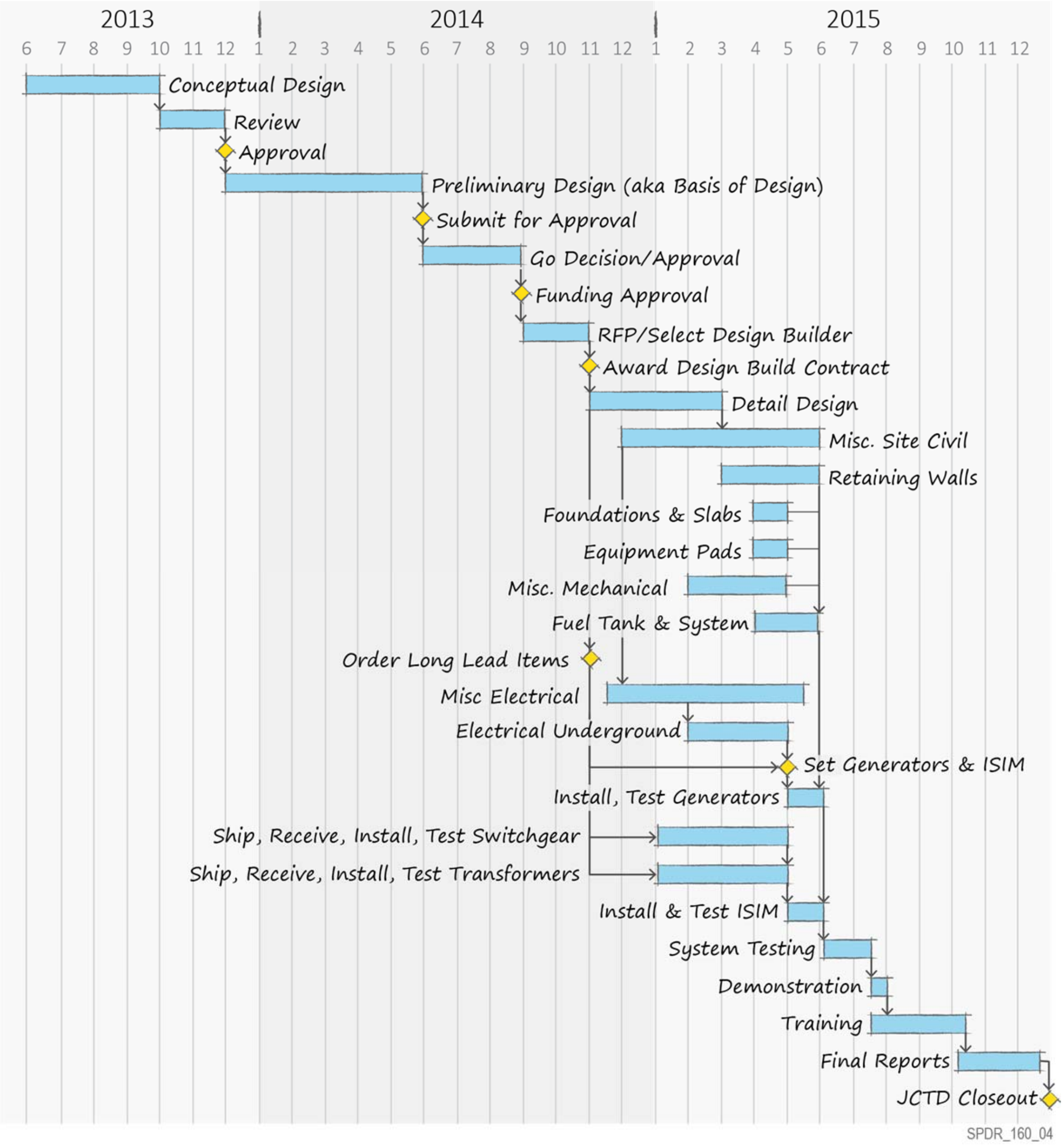


Figure B-12. Example Schedule for Implementing a Cyber-secure Microgrid

Operating Impact

The Design Team used the available meter data to size the Installation JCTD system (see Figure B-13). The prime power plant was sized at a design capacity of 3,000 kW (slightly above annual average base load of 2,725 kW). The design peak load of 3,300 kW with the load of the microgrid discretionary buildings removed (see Table B-1 and Figure B-7) should be less than 3,000 kW. The 3,000-kW target was met with three generator units, each at 1,000 kW. Using three units will allow one unit to swing off line at night and the remaining two will approximately match the design day nighttime load of 2,200 kW minus discretionary load.

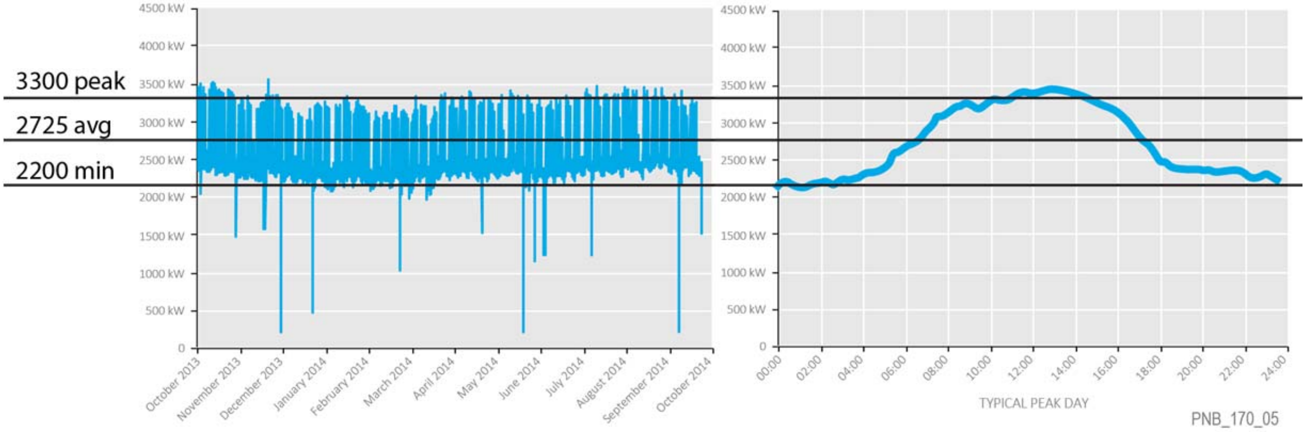


Figure B-13. Comparison of Annual Meter Data and Design Day Data

Integration of renewable solar energy with the microgrid is a strategy for Installation JCTD. Figure B-14 shows how a 500-kW AC solar PV farm power output would integrate with the Installation JCTD design day load.

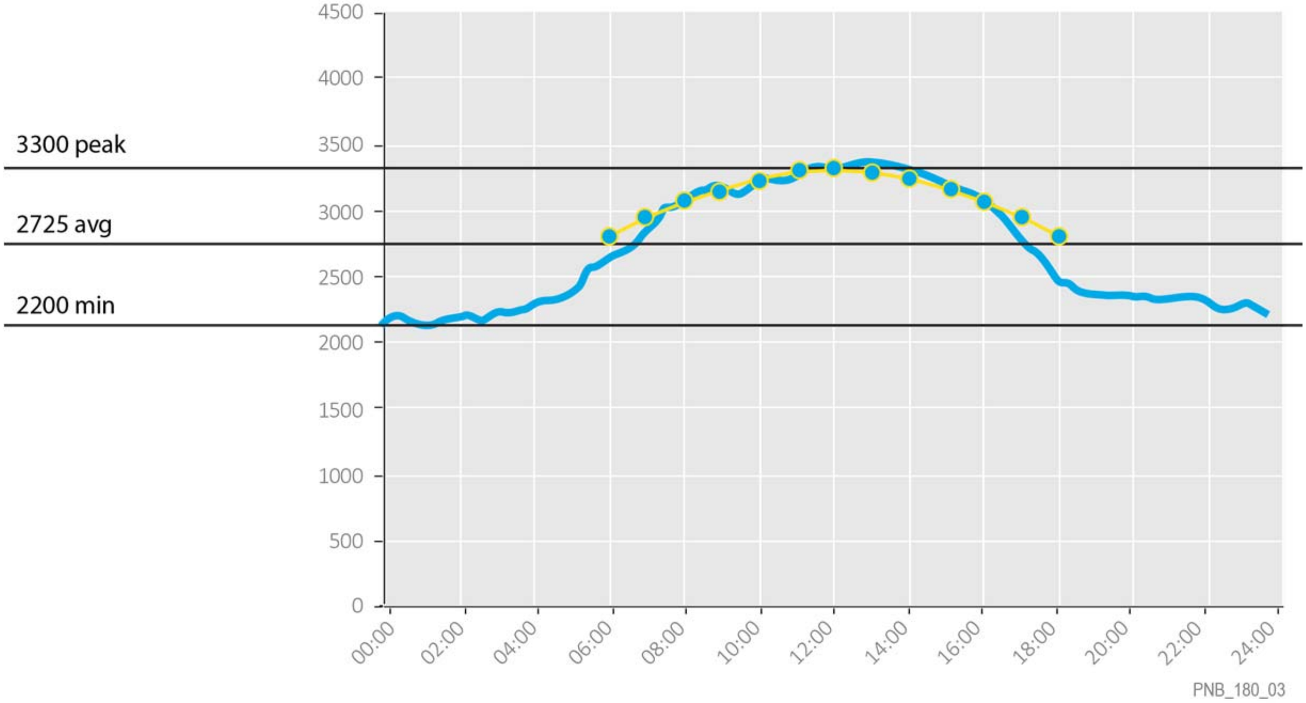


Figure B-14. 500 kW AC Design Day Solar Power Curve Superimposed on Design Day Load Curve

In microgrid mode with assistance of batteries, the prime power system should be able to operate on clear days with only two of the 1,000-kW generators. This will substantially reduce fuel consumption and extend operating time without refueling.

Cost Impact of Solar and Microgrid

Solar Farm: Preliminary estimates of a solar PV farm at Installation JCTD at approximately 500-kW AC power will provide an annual energy production of approximately 900,000 kWh. At the Installation JCTD energy rate, this is worth approximately $135,000. The microgrid can take no credit for this savings because the PV would provide the same savings in the absence of a microgrid.

Microgrid Batteries: Installation JCTD receives an energy cost credit or penalty of 0.10 percent for each 1 percent the monthly power factor deviates from 85 percent. Assuming the annual energy consumption of 23,900,000 kWh, using the microgrid system to improve power factor by 10 percent will save $35,800:

23,900,000 kWh x 10 x 0.10% x $0.15/kWh = $35,800

Solar Farm with a Microgrid: Normally a solar farm would not reduce peak demand, because variable output due to cloud cover would result in inconsistent output. A stand-alone PV system cannot guarantee 100% output every 15-minute period. However, by backing up the solar farm and guaranteeing output with batteries and further backing up the batteries with prime power, Installation JCTD could see full benefit of the solar farm peak power reduction.

500 kW x $21/kW/month x 12 months/year =$126,000

Microgrid and Curtailable Rate Schedule: The microgrid could be used to support a rate schedule modification. If the site agrees to a 2-hour curtailment of a fixed amount of power at a set time of day, the monthly demand charged to the local utility would be reduced by 40 percent of the curtailed demand. The two sets of batteries each have a capacity of 250 kWh. If half of the available energy is used to curtail the load, the savings is $12,600:

(250 kWh/2 hrs.) x 40% x $21 x 12 = $12,600.

Net result – by working in concert, the Installation JCTD microgrid can double the cost savings of the future solar farm.

Appendix C
NAVFAC Platform Enclave and NUMCS

Appendix C: NAVFAC Platform Enclave and NUMCS

The following information on the Industrial Control System Platform Enclave (ICS-PE) and the Navy Utilities Monitoring and Control System (NUMCS) are provided for general understanding, identification of benefits, and control system integration with the two environments based on NAVFAC White Paper documentation for both the ICS PE and the NUMCS. Source documents are from December 2015 and January 2016.

Industrial Control System Platform Enclave (ICS PE) Overview

The ICS PE is a dedicated private enclave providing communications and management of the ICS-CA (ICS-Common Architecture) systems within a NAVFAC Facilities Engineering Command Area of Responsibility (AoR) aligned with current CNIC Navy Regions. The ICS PE provides a common accredited platform, deployed per region, across the enterprise. The ICS PE is deployed to each Navy region and consists of two identical service racks and multiple site router systems to support disparate geographic special areas within the FEC. A subset of the PE will be installed at each installation to provide availability should WAN connectivity be lost. These services are replicated from the regional systems to ensure a consistent cyber security posture throughout the enclave. The ICS PE provides security, management, and encrypted transport services for the regions.

The ICS PE racks will be deployed to NAVFAC Facilities Engineering Commands (FECs) across the enterprise. ICS PE racks will first be deployed to NAVFAC LANT Laboratory for the sole purpose of testing. One installation per FEC/region shall receive two (2) services racks consisting of a security services demilitarized zone (DMZ), a management services zone, enclave border firewall, and intrusion detection system (IDS). The ICS PE contains two primary racks that utilize virtualization technology and redundant hardware and are configured to provide complete N+1 redundancy and failover. The ICS PE will support the control systems across the regions utilizing CNIC PSNet for transport as site-to-site virtual private network (VPN) tunnels. PSnet provides the regions host based security system (HBSS) rollup whereby the ICS PE will roll up to one of two PSnet ePO servers and these servers will, in turn, rollup to Navy Cyber Defense Operations Command (NCDOC). This rollup arrangement provides Information Assurance Computer Network Defense (IA/CND) coverage to the ICS PE which is otherwise isolated from NIPR and SIPR environments.

ICS PE Roles and Responsibilities

NAVFAC CIO is responsible for the configuration, maintenance, management, and IA compliance associated with the all components of the ICS PE as well as for the continued operation of the components and the management of user accounts associated with the operation of ICS PE assets.

ICS PE Benefits

The ICS PE provides the following benefits:

- Provides security for control systems
- Provides a means of inherited controls
- Enables intrusion detection
- Enables secure connections for control systems
- Maintains local functionality if the network becomes unavailable
- Provides Defense in Depth security

ICS PE Integration Overview

Control systems will either be connected, isolated, or integrated with regards to the ICS PE. The most efficient and cost effective means of interacting with the ICS PE is to integrate by utilizing middleware and the Virtual Hosting Environment (VHE) (Namely NUMCS – NAVY Utility Monitoring and Control Systems). Integrated systems will be already accredited and will inherit all security controls of the ICS PE. Connecting systems requires the system to go through accreditation before they can be connected. A connected system inherits the security controls that the ICS PE provides through integration however will not require middleware. If a system cannot be integrated or connected to the ICS PE due to outdated hardware or software or due to being a high risk system, it will be isolated or upgraded. Isolating a system is the most expensive approach as it requires completely disconnecting the system and continuously monitoring it for potential cyber threats.

Navy Utilities Monitoring and Control System (NUMCS)

Naval Facilities Engineering Systems Command (NAVFAC) presently sustains and is responsible for the security of over 1,500 servers supporting millions of building and utility control system (CS) components across the Navy shore enterprise which are composed of hardware and software from 1,700+ manufacturers. NAVFAC's disparate control systems require significant levels of on-site management and inherent cost to address patching updates and security concerns. The large number of unique servers makes it difficult to effectively maintain and manage servers across the command and to ensure accreditation of those systems due to the varying requirements. As a result, current processes for managing and accrediting CS are time intensive and inefficient.

The Navy Utilities Monitoring and Control System (NUMCS) accreditation was created as an enterprise response to NAVFAC's disparate control systems. By leveraging an aggregation of technologies, NUMCS is able to consolidate, secure, and monitor all control systems. NUMCS is a fully engineered and tested solution that provides the infrastructure to support root cause analysis, drive insight through analytics, safe failover through built-in automated fault tolerance, grid incident resiliency, a common accredited platform, and a scalable infrastructure without the need for constant re-accreditation. In fact the Smart Grid analytics is being hosted on NUMCS.

NUMCS Solution Overview

NUMCS was engineered to provide a robust, control system accreditation environment capable of supporting and hosting disparate control system technologies in a cost effective and rapid time to fleet. NUMCS utilizes middleware integration servers and embedded middleware devices to integrate Navy control systems into a common platform, enabling CS operators to manage their respective mechanical and electrical systems securely through a single unified Common Operating Picture (COP). Navy CS initially addressed by NUMCS includes Building Control Systems (BCS) and Utility Control Systems (UCS) such as water distribution and electrical generation and distribution. NUMCS includes a Virtual Hosting Environment (VHE) combined with Software Defined Networking (SDN) that enables colocation and centralization of CS servers while maintaining network integrity and security.

CS components fit in one of two primary categories consisting of components that support the control system through IT like functions which include Ethernet switches and IP network routers and components that support cyber security functions which include controllers, operational software, servers, and workstations. Components supporting cyber security functions are part of the Platform Enclave (PE) accreditation environment. NUMCS provides the accreditation environment to support these components to enable them to perform core operational functions.

NUMCS accredited architecture is deployed in each of nine NAVFAC regions, providing the ability to not only simplify accreditation but also to centrally collect data from all control systems in a given region, and feed this data to business analytics systems to gather insight that can be used to make informed business decisions such as the Smart Grid. The NUMCS architecture provides multi-protocol capability to communicate via hundreds of modern or legacy CS protocols regardless of vendor, which was previously not possible. NUMCS provides the capability for overall electric grid performance analysis that consists of grid incident resilience, fault detection, and post incident analysis.

NUMCS works in tandem with the PE to provide a means of easily deploying and operating control systems in a secure Defense-in-Depth enclave environment that enables the operational control systems that are integrated with NUMCS to inherit the security controls from the PE, providing seamless accreditation and ensuring cybersecurity compliance. Integration with NUMCS enables fault tolerance through real-time mirroring functionality which provides immediate failover in the event of hardware failure or disrupted network communication.

New control systems must be accredited before they can be connected to Navy networks as dictated by DoD standards. However unlike other networks, when an accredited control system is integrated with NUMCS, full additional accreditation is not required due to the software defined networking approach. NUMCS's horizontal and vertical scaling architecture enables new accredited control systems to be efficiently integrated, resulting in both a time and cost savings.

The current capabilities of control system administrators will be enhanced through the consistent and simplified common interface, which will de-couple the different types of hardware and software used by each control system allowing for easier control system management. Control system administrators will be able to more efficiently manage their respective control systems through remote capabilities, such as patch management. The common interface will reduce the potential for error in current processes and increase the administrator's ability to effectively manage control systems in their area of responsibility.

In addition to the added security and efficiency benefits, NUMCS provides a framework for efficient and effective energy management. By unifying all control systems and control system data (including meter consumption data) at each region, energy consumption can be understood and optimized based on current demand. In summary, Smart Grid is the NAVY's enterprise capability that provides analytics for meter data and building and utility energy management. NUMCS will impact our current Navy processes and procedures by increasing control system management, enhancing control system efficiency, and enabling greater control system security.

NUMCS Deployment

Accreditation of the first phase of NUMCS was completed in November of 2015. Phase II accreditation of NUMCS includes upgraded server hardware and will begin when hardware arrives. NUMCS deployment will be in accordance with CIO schedule.

NUMCS Roles and Responsibilities

NAVFAC CIO is responsible for the design, build-out, deployment, configuration, maintenance, management, and cybersecurity compliance associated with all cyber components of NUMCS. NAVFAC Public Works (PW) is responsible for all operational aspects of NUMCS control system applications and embedded field controllers used throughout the system.

NAVFAC CI and other groups which contract work are responsible for incorporating contracting language that sets the requirement for contractors to execute appropriate control system work components within the NUMCS VHE.

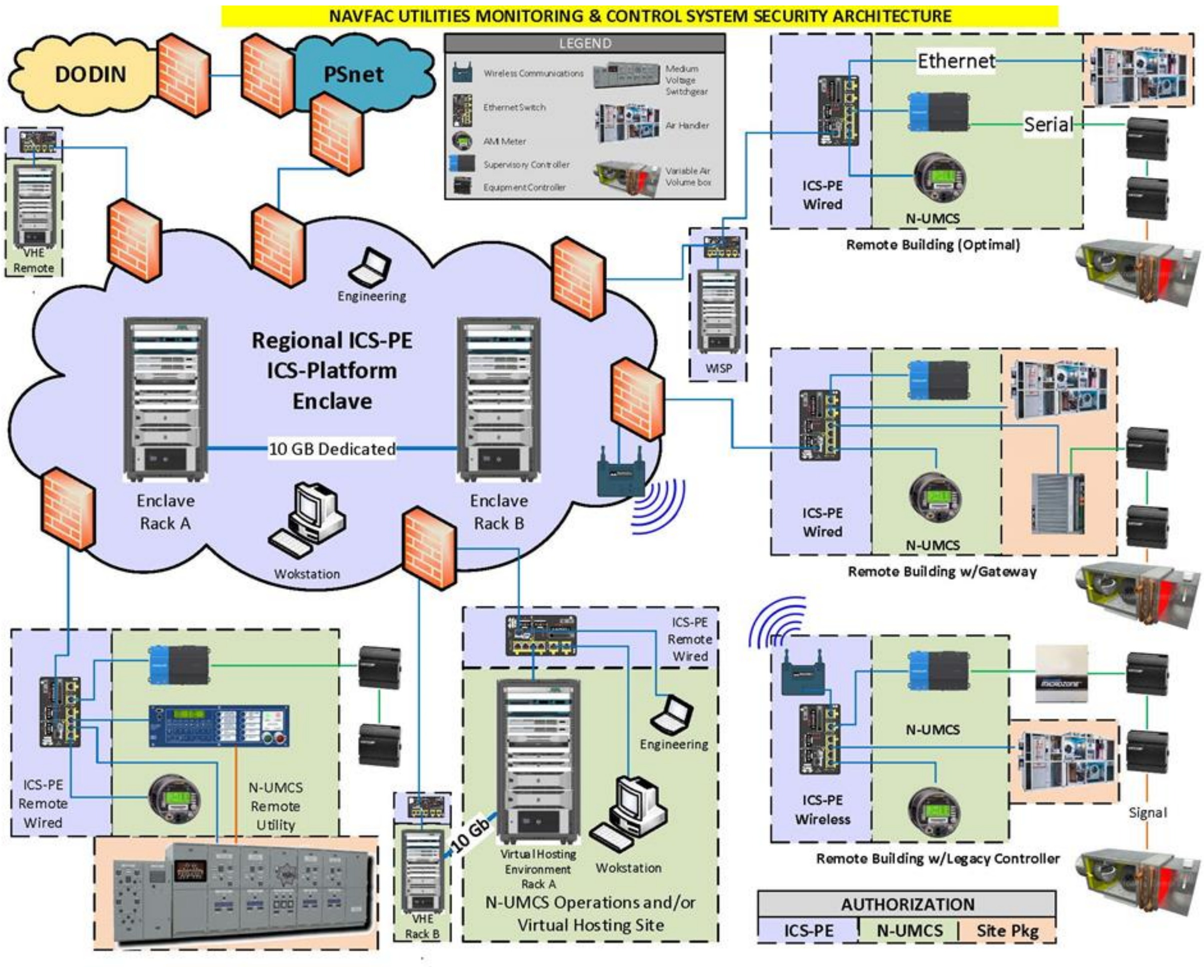
NAVFAC PW is responsible for the operation of applications hosted within the NUMCS VHE and the operational configuration of operational hardware such as supervisory controllers (SC) or equipment controllers.

NUMCS Benefits

NUMCS provides the following benefits to the enterprise:

- Security inherited from the Platform Enclave for operational control systems
- Unify disparate control system servers into a single virtual environment
- Enable streamlined remote patch management
- Provide simplified accreditation of control systems
- Enhance operator capability through a consistent and simplified common interface
- Provide the framework to support more efficient and effective energy management
- Ensure fault tolerance in the event of disrupted network communication
- Enable contractors to focus on controls technology rather than traditional IT hardware and software

ICS PE and NUMCS Architecture



Architecture Walkthrough

The graphic above depicts the ICS PE and NUMCS following deployment. The diagram begins with DoD Information Network (DODIN) which is linked to PSnet. NAVFAC maintains a connection to PSnet through DMZ. The ICS PE, as shown by all areas shaded blue, encompasses all control systems in the region. NUMCS, as shown by the areas shaded green, connects below the ICS PE and provides the accreditation boundary for the region. Some equipment will have its own accreditation boundary and not interact directly with NUMCS as illustrated by the sections shaded orange.